Fatigue Life Estimation of Aluminum Alloy 2024-T4 and Fiber Glass-Polyester Composite Material

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Abstract - *Many engineering parts made of aluminum alloys and composite material are subject to variable stresses like aerodynamic forces. Therefore the current research estimates the mechanical properties of aluminum alloys and composite material under tensile load to find static properties and fatigue test to find dynamic properties. The fatigue test achieved by using reversed bending test machine under constant stress amplitude and stress ratio of (R = - 1). The experimental specimens are divided into two groups at different stress levels. In first group, (18) specimens have been tested with three specimens to each stress range to establish the S-N curve and fatigue limit for aluminum alloy. In second group, (21) specimens have been tested with three specimens to each stress levels establish the S-N curve and fatigue limit for composite materials. It was found that there is a reduction ratio in fatigue limits of glass polyester composite as compared it with that of aluminum alloy. This reduction ratio is about of (1.35-1.54).*

Key Words: fatigue life, Aluminum Alloy 2024-T4, Fiber Glass-Polyester, Composite Material

1.INTRODUCTION

Machine parts which subjected to a repeated reversal or removal of an applied load, fail at a stress much lower than the ultimate strength of material. This type of time-dependent failure is referred to as a cyclic fatigue failure. The failure is due primarily to repeated cyclic stress from a maximum to a minimum caused by a dynamic load. Fatigue has been a major concern in engineering for over 100 years, and there is a very large amount of literature available on the fatigue problem. The importance of a knowledge of fatigue in engineering design is emphasized by one estimation that 90 percent of all service failures of machines are caused by fatigue.

Fatigue failure results from improper design. And because of the case with which complex shapes can be manufactured, the complete rethinking of an established design in terms of composite can often lead to both cheaper and better solution. Below, a review for some of researches deals with the fatigue life for aluminum alloy and composite materials for the last five years.

Roy et al.[1] predicted the low cycle fatigue life of 316L(N) stainless steel based on cyclic elasto-plastic response. The testes carried out at room temperature employing strain amplitudes ranging from ±0.3% to ±1% and strain rate of 3×10-3 s-1. Satrio and Chai[2] studied the fatigue life of woven carbon-epoxy and compared it with the finite element modeling. They found that DMA test, CSR test , and zero stress ratio fatigue test at different temperatures are needed to characterize a material. Ertas and Sonmez[3] proposed a new method to find the optimum fiber orientation angles of composite laminates under various in-plane loads to find the best fatigue life which predict by Fawaz-Ellyin's model. Bendouba et al.[4] investigated the damage of composite materials under two block loading cycle fatigue conditions. Also they studied the effect of loading sequence and the influence of the cycle ratio of the first stage on the cumulative fatigue life. Two loading sequences included high-to-low and low-to-high cases are considered. Vengatesh and Chandramohan[5] presented a survey paper deals with aluminum alloy metal matrix composite and their mechanical properties. Park et al.[6] predicted S-N curves for different stress ratios under variable amplitude loading from the constant life diagram by using limited fatigue experimental data. They developed a nonlinear constant life formulation to estimate more accurate S–N curves for previously developed constant life diagrams. Nair Sarath et al.[7] presented a useful survey study to design engineers deals with aluminum and its alloys and their application in automobile engine components such as engine block, piston and connecting rod. The current research investigates the mechanical properties for aluminum alloys and composite material under tensile load to find static properties and fatigue test to find dynamic properties.

2. MATERIALS

The selected materials for the experimental work are aluminum alloy (2024-T4) and composite material made of polyester as a matrix resin and fibers glass as a reinforcing material.

1.2 The Matrix (polyester)

The material that has been used as a matrix is the unsaturated polyester resin which has many industrial applications because it has a high corrosion and chemical attack resistively. Table l lists the basic mechanical properties of the resin. At room temperature, the chemical reaction that causes the hardening of the liquid resin is a free radical polymerization initiated by organic peroxides. The catalyst used is the methy1 ethey1 ketone peroxide (MEKP) and cobalt naphthenate is added as an accelerator additive[8].

Table – 1: Mechanical properties of the matrix [8]

Properties	Value
Density	1268 kg/m3
Tensile strength	65 MPa
Elongation at break (50mm gauge length)	2.0%
Modulus of elasticity	3. 0 GPa
Poisson's ratio	0.38

2.2 The Fibers

Glass fiber reinforcement is used. Glass fibers are unique materials that exhibit the familiar bulk glass properties of hardness, transparency, resistance of chemical attack, and stability, as well as high strength, flexibility, lightness and process ability. The representative chemical compositions of E-glass is given in Table 2 and the mechanical properties of this type of fibers are given in Table 3[9].

Table – 2: E-glass composition (percentage weight)[9]

Silica	Calcium Oxide	Alumina	Boron Oxide	soda	Calcium fluoride	Total Minor Oxide	Magnesia
54	20.5	14	8	1	1	1	0.5

The relative quantity of the various components of the composite is known as a volume fraction and it is normally expressed as the ratio of volume of reinforcement and to the total volume of the composite. Even the experimental procedure to determine the fiber volume fraction is preferred, the fiber volume fraction analytically of the lamina must be known.
The lamina were weighted and the volume fraction of fibers can be calculated using the formula[10]:

$$v_f = \left[1 + \frac{\rho_g}{\rho_m}\left(\frac{1}{\varphi} - 1\right)\right]^{-1} \quad ......(1)$$

Where v_f is the fiber volume fraction, ρ_g *and* ρ_m are the fiber glass and matrix densities respectively, φ: is the weight percentage of fiber glass in decimal form, $\varphi = \frac{w_g}{w_c}$, and w_g *and* w_c are the fiber glass and composite weight respectively.
It was found that volume fraction of the lamina is 38%.

Table – 3: Mechanical properties of E-glass fibers[9]

Properties	Value
Density	2540 Kg/m3
Tensile Strength	2.45 GPa
Modulus of Elasticity	76 GPa
Yield Elongation	2.6%
Poisson's ratio	0.22

2.3 Aluminum Alloy

The selected aluminum alloy is 2024-T4 which is an aluminum copper. This alloy is used in the wide engineering application due to its desired mechanical properties such as light weight and high corrosion resistance. The nominal and experimental chemical composition percentage weight (%wt) of this material is shown in Table 4.

Table – 4: Nominal[9] and experimental chemical composition percentage weight.

Element	Nominal composition	Experimental composition
Cu	4.4	4.1
Mn	0.6	0.45
Mg	1.5	1.3
Zn	0.25	0.3
Si	0.5	0.2
Fe	0.5	0.3
Ni	-	0.1
Al	remain	remain

3.THE TESTING

Tensile and hardness testing machine (Fig. 1) at laboratories unit/ Alnahrain university have been used to find the mechanical properties of aluminum alloy which are given in Table 5. Each value is an average of three testes.

Fig -1: Tensile and hardness testing machine

Table – 5: Mechanical properties of aluminum alloy.

Property	Standard value	Experimental values
Yield stress (MPa)	325	352
Ultimate stress (MPa)	472	502
Elongation %	20	16
Modulus of elasticity (GPa)	73	80
Hardness (HB)	120	118

Fatigue tests have been performed at laboratories unit/ Alnahrain university according to ASTM standard by using reversed bending testing machine (Avery Antique Testing Machine Type- 7305) as shown in Fig. 2. Under constant stress amplitude and stress ratio of (R = - 1) where R is given by the ratio of the minimum stress to maximum stress applied to the samples in fatigue tests The experimental investigation includes two groups of the specimens at various stress levels. The first group made of aluminum alloy and the second group made of composite material. The standard specimen used is shown in Fig. 3.

Fig -2: Reversed bending testing machine

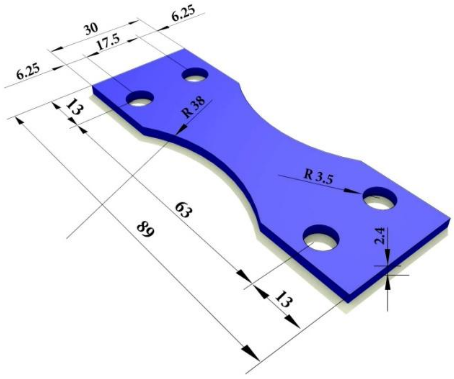

Fig -3: Fatigue test specimen (all dimensions in mm)

In the first group, (18) specimens have been tested with the average of three specimens to each stress level to establish the S-N curve and fatigue limit for aluminum alloy. The alloy were subjected to stress amplitudes of (310, 270, 230, 175, 155, 140) MPa. In the second group, (21) specimens have been tested with the average of three specimens to each stress level establish the S-N curve and fatigue limit. The composite material specimens have been subjected to following stress amplitudes (310, 270, 230, 175, 155, 140, 100) MPa.

The fatigue curve is obtained from many constant amplitude fatigue tests and can be presented by the following equation[11]:

$$\sigma = A N^{\alpha} \qquad \text{.........(2)}$$

where σ is the applied stress amplitude (MPa), N is the number of cycles at which the failure occurs, A and α are constant that can be evaluated by linearization the fatigue curve represented by equation (2):

$$\log \sigma = \log A + \alpha \log N \qquad \text{.........(3)}$$

By using linear fitting and least squares method, α and A can be determined.

3. RESULTS AND DISCUSSION

The fatigue testes results which include the applied stress amplitude and the number of cycles to failure due to applied stress is given in Table 6 for aluminum alloy. From these data, the S-N curve have been drawn. Chart-1 shows the S-N curve of aluminum alloy.

The fatigue behavior of aluminum alloy at constant amplitude load can be described by the following formula:

$$\sigma = 855 N^{-0.109} \qquad \text{.........(4)}$$

And the fatigue limit has been substitute ($N=10^7$) in equation (4):

$$\sigma_{ft} = 855\,(10^7)^{-0.109} = 147.5 \text{ MPa} \qquad \text{.........(5)}$$

Table – 6: Fatigue test results of aluminum alloy specimens under constant amplitude and fully reversed loading (R = -1).

Specimen No.	Stress amplitude (MPa)	No. of cycles at failure N
1	340	4782
2	270	39245
3	230	191429
4	175	1897478
5	155	6367863
6	140	16218322

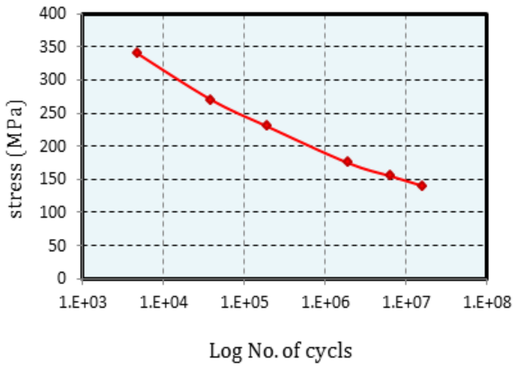

Chart -1: The S-N curve of aluminum alloy.

Also the fatigue testes results for composite material which include the applied stress amplitude and the number of cycles to failure due to applied stress is given in Table 7. From this table, the S-N curve for glass polyester composite have been drawn. Chart-2 shows the S-N curve for glass polyester composite.

Table – 7: Fatigue test results of glass polyester composite specimens under constant amplitude and fully reversed loading (R = -1).

Specimens	Stress amplitude (MPa)	No. of cycles at failure N
1	340	512
2	270	2923
3	230	8076
4	175	88461
5	155	241787
6	140	506823
7	100	7963145

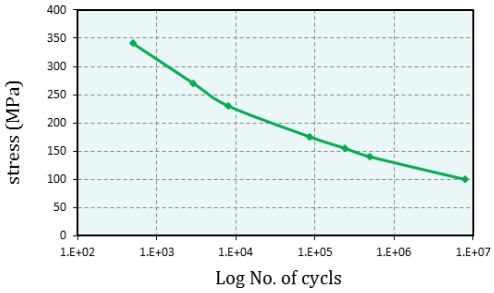

Chart -2: The S-N curve of glass polyester composite.

The fatigue behavior of glass polyester composite at constant amplitude load can be described by the following formula:

$$\sigma = 739.7\, N^{-0.126} \qquad \text{..........(6)}$$

And the magnitude of the fatigue limit at ($N = 10^7$) can be determined from above equation:

$$\sigma_{ft} = 739.7\,(10^7)^{-0.126} = 97 \text{ MPa} \qquad \text{..........(7)}$$

The reduction factor have been determined from fatigue testing results for both aluminum alloy and glass polyester composite under constant amplitude and fully reversed loading (R = -1) and given in table (8). From this table it can be noted that the reduction factor of fatigue life cycle about the rang of (1.35-1.54).

Table – 8: Fatigue test results for both aluminum alloy and glass polyester composite under constant amplitude and fully reversed loading (R = -1)

Specimen	Stress amplitude (MPa)	No. of cycles at failure for aluminum alloy	No. of cycles at failure for glassy polyester composite	Reduction factor in fatigue stress
1	340	4782	512	1.35
2	270	39245	2923	1.39
3	230	191429	8076	1.4
4	175	1897478	88461	1.49
5	155	6367863	241787	1.52
6	140	16218322	506823	1.54
7	100		7963145	-

3. CONCLUSIONS

In this study the fatigue tests have been carried out for aluminum alloy and glass polyester composite at different stress levels. It was found that the life cycles are significantly less for glass polyester composite than that for aluminum alloy at the same applied stress level.

The fatigue behaviour of the aluminum alloy at constant amplitude load can be described by the following formula: $\sigma = 855N^{-0.109}$, while the behaviour of the glass polyester composite can be represented the formula: $\sigma = 739.7\ N^{-0.126}$

The magnitude of the fatigue limit for aluminum alloy and glass polyester composite are 147.5 MPa and 97 MPa respectively.

The fatigue life cycle of composite is reduced by a factor of (1.35 to1.54) as compared with that of the aluminum alloy.

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