Investigation of Fatigue Life of Al 6061-T6 and its Modal analysis

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***Abstract*: Aluminum alloys are widely used in aerospace applications and energy generation due to its strength with respect to low densities. In application they are subjected to different static and cyclic loading conditions, so it is necessary to understand fatigue behavior in those loading condition. The objective of this investigation is to determine the fatigue strength of Aluminum 6061-T6 alloy. Stress and no of cycles are used for description of a fatigue curve. Here we study the effect of natural frequency, modal parameters and mode shape subjected to fatigue loading. And comparing the results of fatigue life prediction model with the experimental fatigue life values. There are two experimental setups required one of them is setup for Fatigue Test Machine in Plane Bending and other one is setup for modal testing.**

***Index Terms*—Aluminum Alloy, 6061-T6**

I. INTRODUCTION

Fatigue failures occur due to the application of fluctuating stresses that are much lower than the stress required to cause failure during a single application of stress. It has been estimated that fatigue contributes to approximately 90% of all mechanical service failures. Fatigue is a problem that can affect any part or component that moves. The fatigue life is the number of cycles to failure at a specified stress level, while the fatigue strength (also referred to as the endurance limit) is the stress below which failure does not occur. As the applied stress level is decreased, the number of cycles to failure increases. Normally, the fatigue strength increases as the static tensile strength increases. Aluminum alloys are widely used for several components of automobile and aerospace industries because of their high specific strength, corrosion resistance, fatigue strength, very low densities and wear resistance. Aluminum is a light material with a density (2.7 g/cm3) that is approximately three times lower than the density of materials such as iron, copper, and brass. Aluminum shows perfect resistance to corrosion under various environmental conditions such as air, water, and sea, as well as under the action of different chemicals.

Aluminum possesses attractive characteristics such as esthetic appearance, machinability, and high electric and heat conductivity. Fatigue is an important parameter for determining the behavior of mechanical parts functioning under variable loads. The fatigue resistance of a structural component is affected by mechanical, metallurgical, and environmental variable factors. Fatigue is the primary reason for 80–90% of engineering failures. In applications that frequently use aluminum composites, determining the fatigue performance of the operating element and the effects of the operating parameters on fatigue is necessary. Fatigue assessment can be typically performed using the S-N (i.e. stress life) or the crack growth method. Establishing extensive databases, including stress–life (S–N) information, is very important for precise evaluation of the fatigue characteristics of an element resulting from different operating conditions.

There are currently three main groups of composite fatigue models, namely,

1. Fatigue life models
2. Phenomenological models
3. Progressive damage models.

Current fatigue life models normally utilize one of the failure criteria as base and an empirical S-N curve as an input. Such fatigue life models can be used to predict the number of cycles to failure but they do not account for the damage accumulation.

II. RELEVANCE/ MOTIVATION OF RESEARCH

Aluminum alloys are widely used in aerospace applications and energy generation due to its strength with respect to low densities. In application they are subjected to different static and cyclic loading conditions, so it is necessary to understand fatigue behavior in those loading condition. The objective of this investigation is to determine the fatigue strength of Aluminum 6061-T6 alloy. Stress and no of cycles are used for description of a fatigue curve.

III. LITERATURE REVIEW

The literature review is presented in this section,

G. Belingardi and M. P. Cavatorta (2006) presented work on bending fatigue stiffness and strength degradation in carbon-glass/epoxy hybrid laminates. Tensile and flexural and controlled bending fatigue tests were conducted with loading parallel to and inclined at 45º to fiber orientation. After fatigue loading with maximum 85% of laminate flexural strength the fatigue tests were stopped at steps of 106 cycles and the damage in the laminate was continuously monitored and the residual properties were measured at every stage. Stress based stress- number of cycles (SN) curves were plotted. It was observed that the amount of stiffness loss and damage for cross ply were significantly more than the angle ply laminates. Reduction in material strength and elastic modulus as measured after 106 cycles was also found to be dependent on the level of fatigue loading and follow different trends for the two sets of specimens.

Ermais Gebrekidan Koricho et al (2014) studied the bending fatigue behavior of Twill E-glass/epoxy composites. Displacement controlled bending fatigue tests with stress ratio R of 0.1 were conducted on standard specimen and damage development in the composite was continuously monitored through the decrease in bending moment during cycling. The specimens were subjected to different loading with maximum value of 75% of the ultimate flexural strength. The amount of stiffness reduction was observed to function of the magnitude of fatigue loading. Different levels of reduction on material strength and elastic modulus were found to be depending on the level of fatigue loading.

J. C. Newman, Jr (2015) presented stress-life (S-N) data from the literature on uniaxial-loaded specimens made of 2024-T351 aluminum alloy and subject to constant-amplitude loading are used to support the crack-growth concept to calculate the fatigue behavior into the giga-cycle fatigue regime using initial flaw sizes consistent with micro-structural discontinuities in the material. Fatigue test data from the literature on uniaxial-loaded specimens made 7075-T6 under superimposed low- (5 Hz) and ultra-high- (20 kHz) cycle (sine-on-sine) fatigue loading are used to study the crack-growth concept for predicting fatigue behavior under giga-cycle fatigue conditions. Fatigue behavior under giga-cycle loading conditions was modelled fairly well with the crack-growth concept.

Catangiu A. et al (2011) presented results of plane bending fatigue experiments conducted on composite plates of orthogonal glass fibers woven and epoxy resin. The set up of plane bending fatigue is described. It is reported that the stratified composite materials have a better fatigue behavior if the angle of fiber direction and the direction of the specimen is lower. Critical numbers of cycles were dependent on the orientation of the reinforcing elements.

Missoum Lakhdar et al (2013) presented vibration analysis as an effective method for damage detection in composite structures. The experimental results were compared with the results obtained by numerical method to validate the approach. It was observed that the natural frequency decreased as the degree of degradation of the rigidity. The location of damage can be determined by comparison with specific vibration mode.

Wicaksono and Chai (2015) proposed a stiffness decay model for prediction of fatigue life of carbon fiber reinforced plastics based on the results of four point bend tests. The proposed model was applied to predict the onset of initial failure and the progression towards final failure.

Prediction of fatigue life by modal analysis:

Experimental modal analysis is a non destructive testing tool used by few researchers to characterize and quantify and the fatigue behavior of materials and thereby to predict the fatigue life.

Moon et al (2003) presented a non destructive fatigue prediction model for composite laminates based on the relationship of the natural frequencies of fatigue damaged laminates under extensional loading to fatigue life. The equivalent flexural stiffness reduction as a function of the elastic properties of sub laminates. Vibration tests were performed to on carbon epoxy laminates to verify the natural frequency reduction model.

M. Abo-Elkheier, et al (2014) presented work on fatigue life prediction of glass fiber reinforced polyester composites using modal testing. The work presented deals with the experimental investigation of the modal analysis of composite laminates to quantify the fatigue behavior. The experimental modal analysis was conducted of the GFRP specimen previously subjected to fatigue loading to determine the modal parameters such as natural frequency, damping ratio and mode shape. The fiber orientation is considered as the main factor affecting the fatigue behavior. The results indicated that the change of modal parameters provide a proper means for predicting the fatigue behavior of composite structures.

Vahid Mortezavi (2016) presented a methodology for evaluating the fatigue of metals in both low and high cycles using the material damping parameter. It is expressed that the limitations of the other methods of fatigue life estimations such as a measurable temperature rise, restricted applications to low cycle fatigue are overcome by the method of fatigue life prediction by using damping parameter. The experiments were conducted for steel to evaluate the changes in damping parameters during fatigue testing. The application of damping parameter for investigating the effect of in-homogeneity of the material and crack initiation duce to cyclic fatigue damage is presented.

IV. RESEARCH FINDING

1. The study was carried out on fatigue behavior under giga-cycle loading conditions was modelled fairly well with the crack-growth concept.
2. The study was presented results of plane bending fatigue experiments conducted on composite plates of orthogonal glass fibers woven and epoxy resin.

3. The study was focused on vibration analysis as an effective method for damage detection in composite structures by numerical method for validation.
4. The study was presented on fatigue life prediction model based on natural frequency changes for tensile –shear spot welded specimens under random loading by rain flow counting method.
5. The study was carried out on methodology for evaluating the fatigue of metals in both low and high cycles using the material damping parameter.

V. Research Issues

From the literature review conducted following research issues are identified,

1. In general fatigue of aluminum alloy materials is a quite complex phenomenon and large efforts are required to be spent on it.
2. Fatigue life prediction models are rarely available for aluminum alloy materials.
3. Aluminum alloy structures are often overdesigned with large factor of safety and extensive prototype testing is required to allow for an acceptable life prediction.
4. Majority of the research work is related to the tension-tension fatigue and tension-compression fatigue but less work is reported in bending fatigue life estimation.
5. Prediction of fatigue life based on modal testing a nondestructive testing tool is an emerging approach as and has great potential.
6. Prediction of fatigue life based on modal testing for Aluminum alloy is not reported.

VI. Problem definition

Fatigue of Aluminum alloy materials is a quite complex phenomenon. Due to the deficiencies in the current life prediction methods for these materials, aluminum alloy structures are often overdesigned with large factor of safety and extensive prototype testing is required to allow for an acceptable life prediction. The approach of predicting the fatigue strengths on basis of S-N curves is not appropriate for aluminum alloy and a new approach should be adopted for the fatigue life prediction.

VII. Research Objectives

The specific objectives of the research work are as described below,

1. The main objective of the research work is to investigate the application of experimental modal analysis to quantify the fatigue behavior of aluminum alloy in plane bending.
2. To study the effect of natural frequency, modal parameters and mode shape subjected to fatigue loading.
3. To quantify the effects of modal testing for prediction of fatigue behavior of aluminum alloy.
4. Compare the results of fatigue life prediction model with the experimental fatigue life values.

VIII. Scope of Proposed work

The proposed research work described in following steps,

1. Fabrication of test specimens of selected Aluminum alloy.
2. Performing the bending tests on the fatigue testing machine according to ASTM 8
3. Interrupting the tests at regular intervals and carry out the modal tests on the same test on the same specimen with FFT analyzer.
4. Measurement of natural frequencies for the variations in lamina.
5. Prepare the S-N curves by curves fitting technique.
6. Quantify the fatigue behavior of the aluminum alloys under modal testing and use it for prediction of fatigue life.
7. Establish empirical equation that correlate the fatigue life to natural frequencies and damping ratio.

IX. Research Methodology

The main objective of this research is to apply the modal analysis as a nondestructive tool for the estimation of fatigue life of aluminum alloy under different loadings. The experimental work involves fatigue testing and modal analysis of aluminum alloy work specimens under different loading conditions. The research will deliver the fatigue life prediction models for aluminum alloy under different loading.

X. Experimental Work

Two set ups are required for the research work as described below,

1. Experimental set up for Plane Bending Fatigue Testing
2. Experimental set up for modal testing

There are two experimental setups required for the work as

1. Fatigue Test Machine in Plane Bending

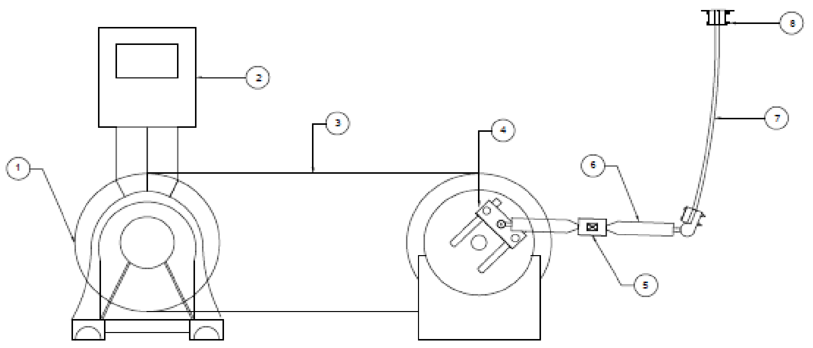

Figure 1. Schematic diagram of experimental setup for Plane Bending Fatigue Testing

1. Single Phase Electric Motor
2. Speed Control Unit
3. Belt Drive
4. Eccentric Cam
5. Load Cell
6. Work Specimen
7. Connecting Rod
8. Holding Frame

Figure 1. shows the experimental set up for fatigue testing in plane bending. The experimental set up have some essential components and that are a single phase electric motor, belt and pulley drive, controlling and data recording system, eccentric cam, holding arrangement and test specimens etc. An eccentric cam is used for converting the rotary motion of the output shaft of pulley into the purely symmetric and oscillating motion of the work specimen. The work specimen is fixed at one end and oscillating at the other end offering alternative bending motion. The stresses are measured with the help of load cells. The numbers of cycles are recorded with the help of data acquisition system.

2. Experimental setup for modal testing.

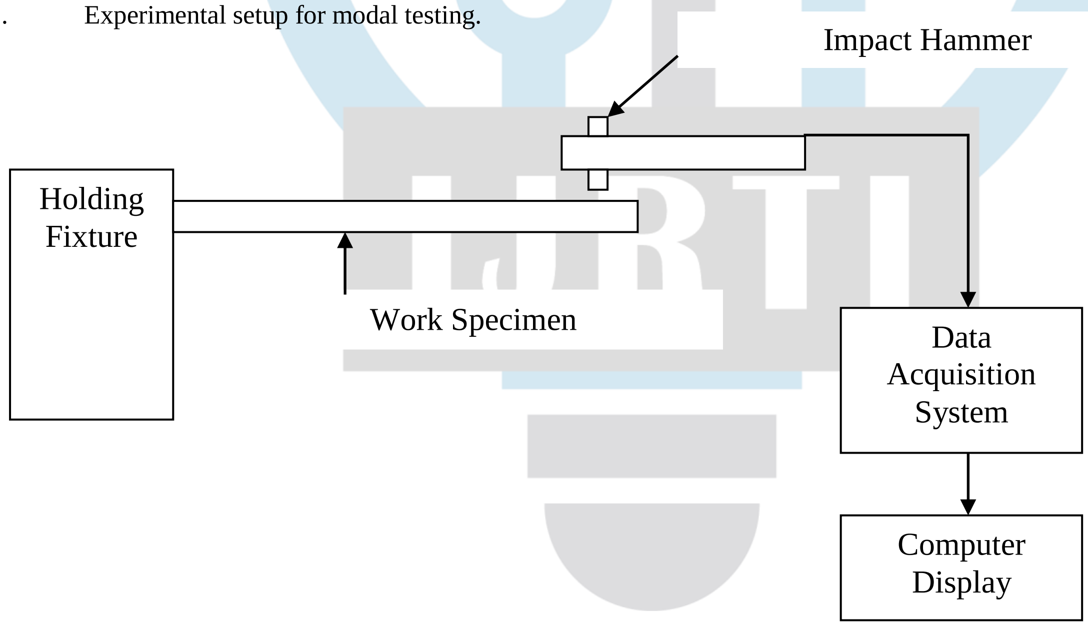

Figure 2. Block diagram of experimental setup for modal testing

The experimental set up for the modal analysis is shown in figure 2. The work specimen is held in the fixture at one end is free at the other end. The excitations are given with impact hammer with accelerometer and the natural frequencies are noted at different modes and the frequency response functions are obtained.

XI. Expected Outcome

The research will deliver the fatigue life prediction models for aluminum alloy under different loading

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