Design & Development of Bending Fatigue testing Machine for Composite Materials

Mr. Sagar Madhukar Landge[1], Miss. Dhanshree Nilesh Patil[2], Mr. Aakash Vijay Talekar[3], Mr. Anit Ajit Ghosh[4], Prof. Mr. Mainak Bhaumik[5]

[1,2,3,4] U.G. Students in M.G.M's Collefe of Engineering and Technology, Kamothe, Navi Mumbai
[5] Assistant Professor in Department of Mechanincal Engineering, M.G.M's College of Engineering and Technology, Kamothe, Navi Mumbai

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Abstract – *Fatigue failure is the cause due to cyclic loading. These types of failure occurs mainly in systems operated by motor, Continuous force and moment but varying magnitude. The literature shows that fatigue data of composite materials is not commonly accessible because of high cost and Availability of machines. Many designs are developed with complex mechanism and high operating cost. The aim of this project work is to design a fatigue testing machine for both tensile and bending loading with simple operating technic and low cost of testing. Concept designing and 3D Modeling will be done using Solidworks 3D designing Software and Fabrication of machine and Testing of specimen will be done and S-N Data will be generated. These types of machine will helps the engineers to study the behaviour of the component made of composite materials .i.e. In case of Aeroplane Body at low cost and Handling Process. These Machines will be manufactured at low cost and can be operated without skilled man power.*

Key Words: Bending Fatigue, Solid Model, Composite Material

1. INTRODUCTION

Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit. Hence, it is necessary to test material for their fatigue life. Fatigue machine and S-N data of maximum metals are already available.

Composite Materials are the New Era of materials. Still lot of work is going on to test their performance. Different composite materials have different fatigue life characteristics for different fiber materials and fiber orientations and hence they will have different fatigue data for different combination of matrix and reinforcement. Because of unavailability of machine and Costly Process, Fatigue data of composite are not commonly available. In this paper an attempt is made to design a simple system which helps engineers to generate the fatigue data easily and at low cost both types of loading conditions bending. Metals produce same fatigue data for Linear, transverse and bending type of loading because of Isotropic property assumption.

But Composite behaves differently for different types of loading because of fiber stacking. In Maximum cases, composites are subjected to bending loading, that is the reason Composite flexural strength data i.e. S-N data is needed to check the feasibility of composite to find its life cycle strength. The aim of this project work is to design a machine which can measure fatigue data for bending loading of composite materials.

1.1 Working principle of the fatigue testing machine

The experimental set-up was developed specially for flexural fatigue tests on cantilever beam specimens. Although more sophisticated commercial servo hydraulic testing machines are capable of performing the same fatigue experiments, the maintenance and service costs are very high, compared to the costs of use of this testing machine. The power is transmitted by a V-belt to a second shaft, which provides a fatigue testing frequency of 2.23 Hz. The second shaft bears a crank-linkage mechanism, which is shown in the 3D Design. This mechanism imposes an Alternating displacement on the composite sample that connects the linkage with the lower clamp of the composite specimen.

At the upper end, the specimen is clamped. Hence the samples are loaded as a composite Cantilever beam. The amplitude of the imposed displacement is a controllable parameter and the adjustable crank allows to choose between single-sided and fully reversed bending. The deflection can vary from zero to the maximum deflection in one direction, or in two opposite directions, respectively.

A full Wheatstone bridge on the linkage is used to measure the force acting on the composite specimen. The selection of the strain gauges had to be done carefully, since the linkage is fatigued as well and internal energy dissipation leads to small temperature rises at the site of the active strain gauges, which are not compensated by dummy strain gauges in the neighbourhood. Therefore two self-temperature compensated strain gauges are placed on the two opposite surfaces of the linkage and they measure both the longitudinal and transverse strains. In that way temperature effects, as well as small bending moments, are compensated.

1.2 Types of Fatigue Failure

1. High Cycle Fatigue
2. Low Cycle Fatigue

High Cycle Fatigue

When the fatigue occurs above 10^3 cycles it is usually called High-cycle fatigue. In high-cycle fatigue situations, materials Performance is commonly characterized by an S-N curve, also Known as a Wohler curve. The deformation is in elastic range.

The S-N curve for a specific material is the curve of nominal stress S against the number of cycles to failure N. A log scale is almost always used for N. The stress is usually nominal stress and is no adjustment for stress concentration. The curve is usually obtained one by reversed bending experiments with zero mean stress. The S-N curve of 1045 steel and 2014-T6 aluminium alloy is enclosed below to represent two typical S-N curves of metal materials

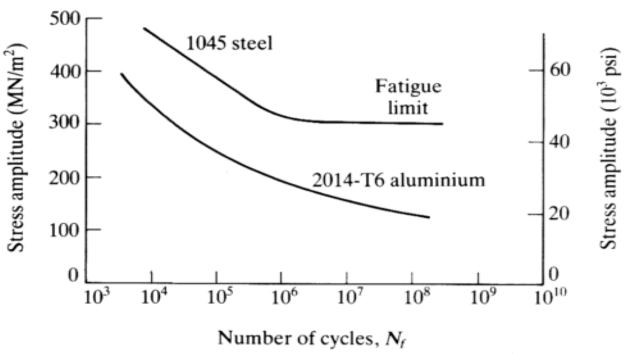

Chart -1: High Cycle Fatigue

Low Cycle Fatigue

Where the stress is high enough for plastic deformation to occur, the accounting of the loading in terms of stress is less useful and the straining the material offers a simpler and more accurate description. This type of fatigue is normally experienced by components which undergo a relatively small number of straining cycles.

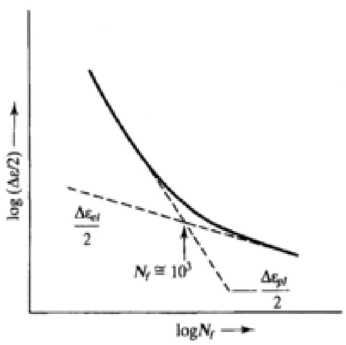

Chart -2: Low Cycle Fatigue

1.3 Fatigue failure in composite material

The subject of damage and failure of composite materials under static and time varying. Loads is broad with many aspects ranging from the mechanisms involved to the mechanics. Methods of analysis to failure criteria and life prediction. When a composite structure is subjected to a general time-varying load, e.g. a cylinder under cyclic bending and torsion or a panel under cyclic biaxial tension, the failure of the Structure is often determined by failure of fibres in the critical load bearing ply. That ply could in general be stressed by in-plane stresses. The fatigue Failure of the critical ply can be viewed as occurring due to the primary mechanism of fibre failure modified by other mechanisms such as matrix cracking and fiber deboning.

1.4 Characteristics of Fatigue

- In metal alloys, and for the simplifying case when there are no macroscopic or microscopic discontinuities, the process starts with dislocation movements at the microscopic level
- Fatigue is a process that has a degree of randomness often showing considerable scatter even in seemingly identical sample in well controlled environments.
- The greater the applied stress range, the shorter the life.
- Fatigue life scatter tends to increase for longer fatigue lives.
- Damage is cumulative. Materials do not recover when rested.
- High cycle fatigue strength can be described by stress-based parameters.
- Low cycle fatigue is associated with localized plastic behavior in metals.
- A strain-based parameter should be used for fatigue life prediction in metals.

Fatigue Failure in Ductile Material

Ductile failure is characterized by tearing of metal and significant plastic deformation. The ductile failure may have a gray, fibrous appearance. Ductile failures are associated with overload of the structure or large discontinuities. This type of failures occurs due to error in design, incorrect selection of materials, improper manufacturing technique and handling.

Fatigue Failure in Ductile Material

Brittle failure is characterized by rapid crack propagation with low energy release and without significant plastic deformation. Brittle metals experience little or no plastic deformation prior to failure. The failure may have a bright granular appearance. The failures are generally of the flat type and chevron patterns may be present. Materials imperfection, sharp corner or notches in the component, fatigue crack etc.

Overview:

Fatigue failure is the most dangerous failure criteria even in ductile materials as the failure is very sudden without any indication and may prove detrimental to human life and property. Hence, it becomes very necessary to know the behavior of materials under cyclic loading. Composite materials made up of same material but with different fiber volume and fiber orientation will have different fatigue life. Hence, their life is to be tested which is a very costly process. A cheap and generic alternative is to be therefore developed.

With considering objective to design the fatigue testing machine for Composite Materials for its bending Characteristics & To develop the machine and to obtain fatigue characteristic of the composite specimens in this paper use following methodology.

Generating a conceptual design of mechanisms by trial and error Method.

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3D modelling of the final design in CAD software.

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Motion study of the Generated mechanism

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Selection of Motor, Roller mechanisms, clamping assembly etc.

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Fabricating the final design.

Chart -3: Methodology

2. CONCEPT DESIGN MODEL

Concept design is the very first phase of design, in which drawings or solid models are the dominant tools and products. The concept design phase provides a description of the proposed system in terms of a set of integrated ideas and concepts about what it should do, how it should behave, and what it should look. It includes the design of interactions, experiences, processes and strategies. It helps to create a user interface which is easy to understand and interpret.

2.1 First concept of Fatigue testing machine

In this design, Kinematic mechanism is design in such a way that only bending load is possible to apply on composite sample. This mechanisms is rotated by the help of AC motor which oscillates the connecting rod which in terns connected to the Crank which applies the bending load on the composite sample. In this Mechanism, composite sample is fixed at the top and free to apply the bending load on the free end.

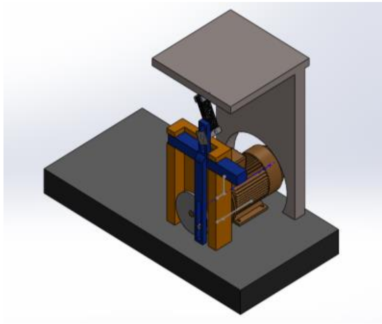


Fig -1: First concept of the fatigue testing machine

2.2 Second concept of Fatigue testing machine

In this mechanism Eccentricity of the connecting can be varied to apply bending deflection from 0 to maximum. This concept is very compact in size and Designed efficiently. Vertical frame is designed to mount the composite sample vertically and free length of the sample can be varied to check the fatigue data for different free length. Power transmission from motor shaft to second shaft is done using belt and pulley mechanism

Fig -2: Second concept of the fatigue testing machine

2.3 Third concept of Fatigue testing machine

This is the final concept design which will fulfil all the requirement of the project i.e. bending loading on the composite sample in a single machine. Same sample can be tested for bending failure in a single machine to find the fatigue characteristics of the composite sample. A separate mechanism is design to apply the bending load in the linear direction to the sample using sliding mechanism.

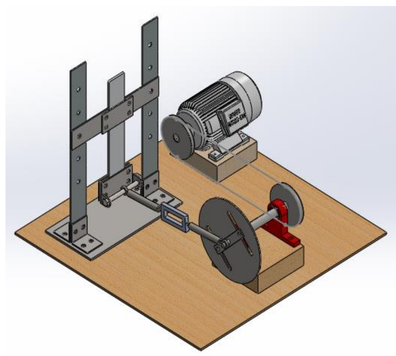


Fig -3: Third concept of the fatigue testing machine

2.4 Different parts of the Design

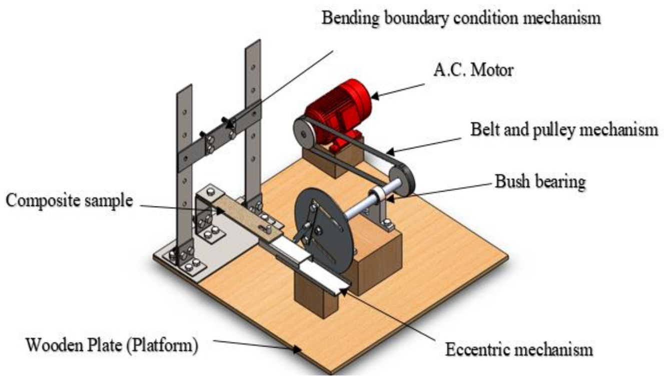


Fig -4: Parts of Design

Solid works software is used to design the detail dimensions of the finalized model. This software will help the designer to understand the actual working of the mechanism before going to manufacturing. This type of designing helps in cost saving in research and development.

3. SELECTION OF COMPOSITE MATERIALS

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure.

E-glass and S-Glass composite materials are selected for the testing of the fatigue life. This selection is made on the basis of availability of raw material in the market, cost and ease of manufacturing. Fatigue data of the E Glass composite materials is available in the open source which will help us to validate the fatigue data with the standard data available in the market. S- Glass Fatigue data is not available in the open source so, is selected to check the fatigue data of non-Available material. This helps in validation of the experiment and identifying data for new material too.

3.1 Properties of E-Glass and S-Glass Composites

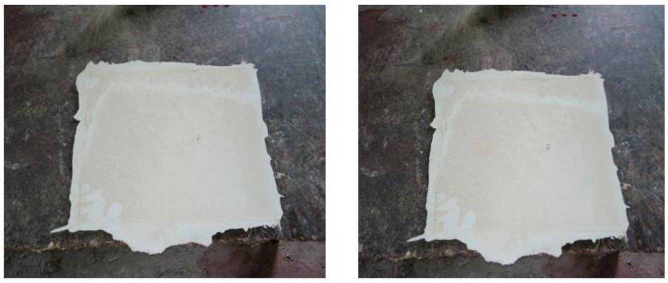
Table -1: Properties of Composite material

Properties	E-glass	S-glass
Young's modulus (GPa)	72	86
Poisson's ratio	0.21	0.21
Density (Mg/m^3)	2.55	2.485
Tensile strength (MPa)	1520	4700
Specific heat (J/kg.K)	800	735

Composite Sample Details

The plain woven glass fabric was stacked in eight layers.

All the layers are placed in loading direction. All composite specimens were manufactured using Hand lay Mold technique. After curing they had a thickness of 2.72 mm. The samples were cut to dimensions of 145 mm long by 30 mm wide E-glass and S-Glass composite materials are selected for the testing of the fatigue life. This selection is made on the basis of availability of raw material in the market, cost and ease of manufacturing. Fatigue data of the E Glass composite materials is available in the open source which will help us to validate the fatigue data with the standard data available in the market. S- Glass Fatigue data is not available in the open source so, is selected to check the fatigue data of non-Available material. This helps in validation of the experiment and identifying data for new material too.



S-glass E-glass

Fig -5: Manufacturing images of Composite samples

3.3 Material Selection for each Parts

Table -2: Material Selection of Parts

Sr. No	Parts	Materials
1	20 mm Diameter shaft	Structural Steel
2	Bearing 20mm inner diameter and 30mm outer Diameter	Stainless Steel
3	Circular Disc with Slot	Structural Steel
4	Composite Sample	E Glass and S Glass
5	Base Plate	Wood
6	Metallic Frame	Mild Steel

3.4 Manufacturing Cost

Table -2: Material Selection of Parts

Sr. no	Parts	Cost in Indian Rupees
1	2KW 1000RPM Motor	2200/-
2	Strain Gauge type Load Cell	510/-
3	Shaft, Bearing and Metal Frame Material Cost	2000/-
4	Composite Material Sample Cost	500/-
5	Labor Cost	3500/-
	Total Cost	8710/-

3. CONCLUSION

The setup is cheap, efficient and does not requires a lot of space like the conventional fatigue testing machines available in the market. Development of the component made up of the composite material. Hence the many composite materials samples can be tested for bending fatigue testing with the help of this setup.

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