Structural and Fatigue Analysis of Pinned Joints

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ABSTRACT

The application of physics and engineering in designing, manufacturing and maintenance of mechanical systems is an important part of mechanical engineering. In this discipline, there are plethora of ways and means in which two objects can be fastened together. A solid cylinder-shaped device known as pin joint is widely used to connect compatible objects at joint areas in the real world systems. Here the type of joint connection plays an important role in the successful connection of objects. Pint joint is typically used in most of the mechanical devices as it is flexible. Such joint can be subjected to welding or allow free movement between the connected objects. In this paper, we present a methodology for structural and fatigue analysis of pinned joints. E Glass and S2 Glass epoxy composite plate is considered. Two serial holes are used that have varying distance from the free edge of the plate. A composite plate is made and the fatigue analysis of pinned joints is made. Cosmos is used for structural and fatigue analysis. The empirical study revealed that the proposed approach is capable of analyzing fatigue of pinned joints.

Key Words: Fatigue analysis, pinned joints, fastening of objects

INTRODUCTION

A composite material is the material which is made up of two or more materials. The materials used for composite material might have different characteristics. However, when two or more materials are mixed as per the engineering principles of mechanical engineering, the resultant material can have unique characteristics that are very useful. However, identification of materials in composite material is possible as the materials do not dissolve or be converted to other ones. There are many instances in nature where the combining of multiple materials to form new materials as shown in Fig. 1. The materials when combined get different features which are unique and may not existing in the constituent materials.

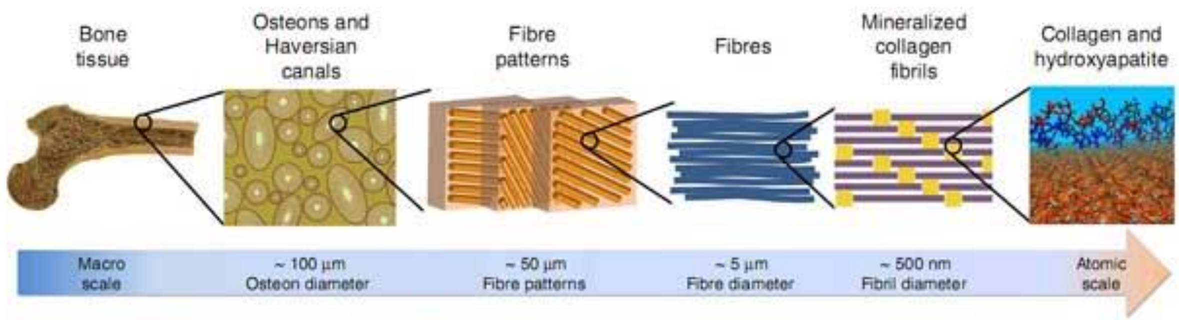


Figure 1 – Materials combination and dynamics of characteristics

Many researchers contributed towards the mechanical engineering in terms of fusion of two or more materials to form new material. The investigation into the effects of staking objects was made in [1]. Experiments were made on bolted woven composite objects and their strengths [2]. Pin-loaded holes and the layered composites, their strengths and the failures were analyzed in [3]. More works related to this can be found in literature review section of this paper.

Our contributions in this paper include the design and implementation of a methodology that helps in structural and fatigue analysis of pinned joints. We made an empirical study to analyze the fatigue of pinned joints using Cosmos. The remainder of the paper is structured as follows. Section II reviews literature on prior works. Section III presents proposed methodology. Section IV presents experimental results while section V concludes the paper besides providing directions for future work.

LITERATURE REVIEW

Khashaba [1] studied the stacking effect of a sequence of failure loads with respect to strength. His research also involves the pinned – joints. The experiments also involve epoxy composite laminates which are glass-fiber reinforced. The investigations were made on specimens like $[0/90]_{2S}$, $[15/-75]_{2S}$, $[30/-60]_{2S}$ and $[45/-45]_{2S}$ and stacking sequences are studied both numerically and experimentally. On unidirectional $[8]_0$ glass-fiber which is reinforced composite laminate are used for ASTM tests. The tests are conducted to know the characteristics of single lamina which is very essential for finite element analysis. With the aid of ABAQUS software, a 3D progressive damage model was planned to implement through simulations. The empirical results revealed that the highest ultimate strength is associated with the laminate $[0/90]_{2S}$. In the same fashion, the ultimate strength and minimum bearing was associated with the laminate $[30/-60]_{2S}$. Shear-out failure mode for $[0/90]_{2S}$, $[15/-75]_{2S}$ and $[30/-60]_{2S}$ was resulted when loading the specimens to max value. This is done when sequences are stacked. The stacking sequences with speciments [45/-45]2s leads to failure mode. The numerical and empercal results reveal that there an is agreement of results with Euclidean error norm of 8.57%.

F. Pierron [2] made a numerical and empirical study on bolted woven composite joints with respect to their streangth and stiffness. The purpose of this research was to find out the possible prediciotn of characteristics of joints obtained from the materials used for experiements. Later another model was developed which is a refined finite element model where nonlinearities are obnserved. They are due to contact angle between hole and pin and materials used for the purpose. Influence of the clearance was given specific attention while making experiments as it is very important. The research concludes that there was good agreement between the numerical results and empirical results. Ivana Ilic etc [3] used a com putation method meant for failure analysis on layered composites that have pin-loaded holes. The research focused on the making a reliable approach for computing and analyzing intial failure load for such holes in layered composite structures. Stress distribution is around the fastener hole which is determined using Finite Element Method (FEM). In order to determine the joint failure Tsai-Wu intial failure condition and Chang-Scott-Springer property curve approaches are combined. Pin-load distributions were given highest attention in order to determine the failure at load level and its localization. The prior work to this was focused on the cosine distribution between the lug and pin which was mechanically fastened joint. The failure analysis was carried out using that. The observations reveal that the stacking of seuquences of layered composites that are having pin-loaded holes was made. Failure load in composites and mode analysis with stacking sequence [0/(±45)3/903]S is given important attention. The results are compared with experimental results and good correlatins are found.

H.M. Harsha et al. [4] focused on investigating the dynamics of bearing or failure load of filler. The composites were used with single or double pinned joints that are having different characteristics and subjected to various methods of experimentation. The effect of the distance between the first hole and diameter and the width of plate to W/D ratio and filler effect were experimented on Zinc Sulphide (ZnS) and Titanium dioxide (TiO_2) with respect to bearing load. Laminated woven glass biber composite plate containing double and single serial pinned joints were used for experiments.

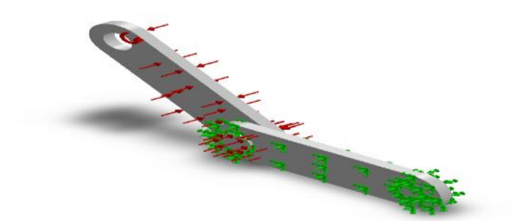
Larry B. Lessard et al. [5] studied the modeling of damage in laminated composite materials. Such material contains complexity and prone to failure process due to difficulties. Stress concentrations are more in joint region and there is complicated stress in the observations. For modeling progress damage right from the start to the end the approach used is finite elements methods. They avoided usage of closed form stress analysis for obvious reasons. For finite element technique, there are two approaches. They are non-linear models and simple two-dimensional linear model. When non-linear material is used, its behavior is analyzed using deformation theory and two enhancements are observed in the model. There should be logical combination of appropriate material characteristic degradation rules and suitable failure conditions.

STRUCTURAL ANALYSIS OF PINNED JOINTS USING S2 GLASS FIBER

This section provides details of the experiments and the study in terms of model information, loads and fixtures, mesh information and related details. These details can help in understand ing the procedure followed for the empirical study and the results reveal that significance of the study.

MODEL INFORMATION

This sub section provides model information that provides the details in terms of model name and the current configuration. This is further used in the empirical study and derivation of results of the experiments.



Model name: asm0004_asm

Current Configuration: Default

Table 1 – Model information

As can be seen in Table 1, the model information is presented that will be useful in understanding and completion of the experiments that focus on studying and analyzing the fatigue of pinned joints when two materials are combined.

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details	
Fixed-1		**Entities:** **Type:**	**4 face(s)** **Fixed Geometry**
Resultant Forces			

Components	X	Y	Z	Resultant
Reaction force(N)	**0.068675**	**-0.017952**	**-0.348679**	**0.35583**
Reaction Moment(N·m)	**0**	**0**	**0**	**0**

Table 2 – Loads and Fixtures

As can be seen in Table 2, it is evident that the details are given in terms of fixture name, its visual appearance, and fixture details in terms of type and entities. The resultant forces are also shown in terms of components, reaction force and reaction moment.

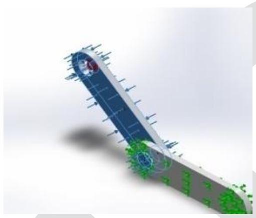
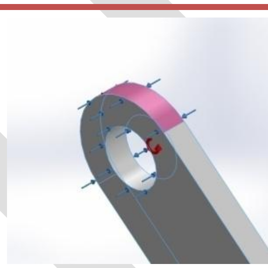
Load name	Load Image	Load Details
Pressure-1		**Entities:** 4 face(s) **Type:** Normal to selected face **Value:** 6.99 **Units:** N/mm^2 (MPa)
Centrifugal-1		**Centrifugal, Ref:** Face< 1 > **Angular Velocity:** 4 rad/s **Angular Acceleration:** 0 rad/s^2

Table 3 – Other loads

As can be seen in Table 2, it is evident that the details are given in terms of fixture name, its visual appearance, and fixture details in terms of type and entities. Value and units are given to pressure -1 while the centrifugal reference value, angular velocity and angular acceleration are provided for centrifugal – 1.

Mesh Information - Details

Total Nodes	12838
Total Elements	7408
Maximum Aspect Ratio	10.937
% of elements with Aspect Ratio < 3	99.6
% of elements with Aspect Ratio > 10	0.027
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	WINCTRL-8MTEE6B

Table 4 – Mesh information

As can be seen in Table 4, it is evident that mesh information is provided in terms of total nodes, total elements, maximum aspect ratio and their dynamics with given threshold. It also shows information about computer name and timeout to complete mesh.

Results of the Study

The empirical study has resulted in many interesting facts which are presented in Table 5. The results are provided in terms of stress, type, min and max values. The empirical dynamics of displacement and also strain are provided in Table 6 and Table 7 respectively.

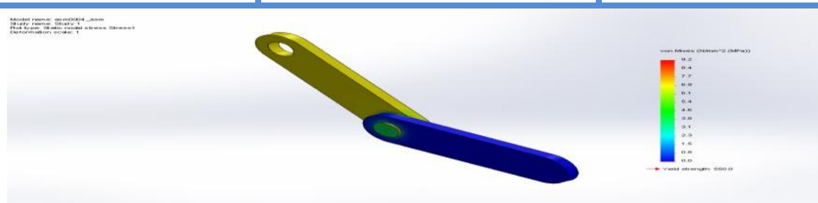
Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.32226e-014 N/mm^2 (MPa) Node: 10854	9.2013 N/mm^2 (MPa) Node: 12758
 asm0004_asm-Study 1-Stress-Stress1			

Table 5 - Stress

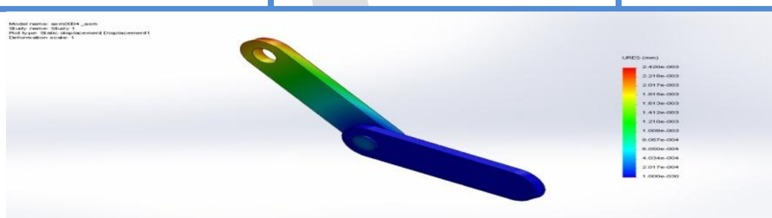
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 16	0.00242016 mm Node: 326
 asm0004_asm-Study 1-Displacement-Displacement1			

Table 6 – Displacement

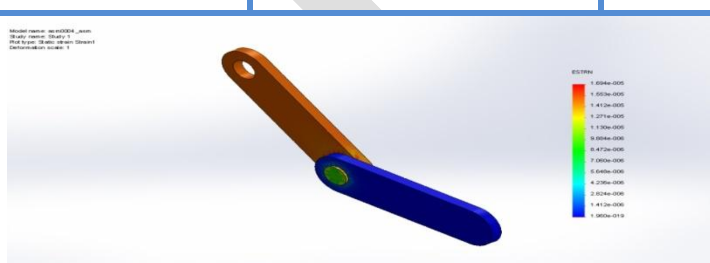
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.95961e-019 Element: 6052	1.69445e-005 Element: 2212
 asm0004_asm-Study 1-Strain-Strain1			

Table 7 - Strain

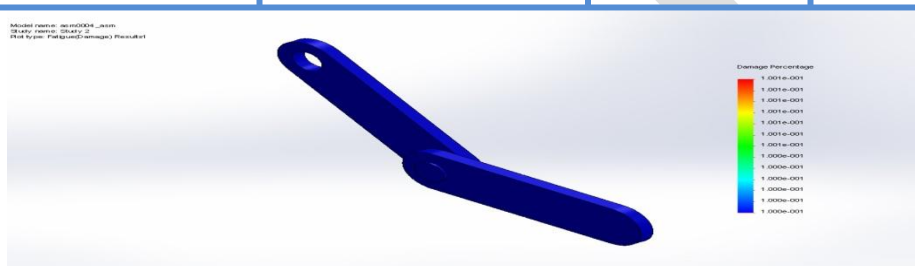
The results presented in Table 5, 6, and 7 reinforce the facts and figures that are related to the experiments. The results are provided in terms of stress, strain and displacement. Min and max values besides the type are considered for result analysis.

FATIGUE ANALYSIS

Study Results

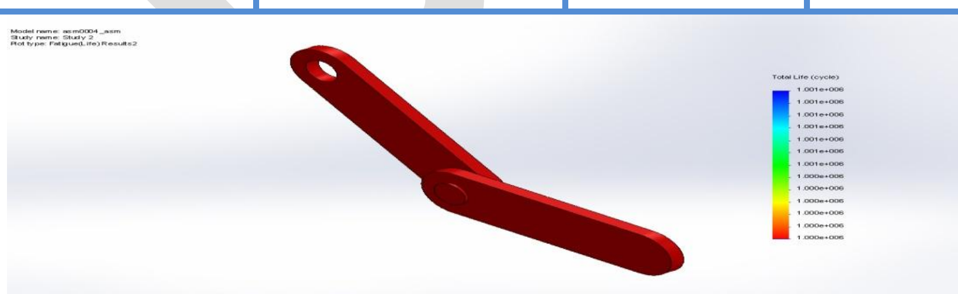
This sub section provides results of fatigue analysis with descriptions such as type, min and max values.

Name	Type	Min	Max
Results1	Damage plot	0.1 Node: 1	0.1 Node: 1



asm0004_asm-Study 2-Results-Results1

Name	Type	Min	Max
Results2	Life plot	1e+006 cycle Node: 1	1e+006 cycle Node: 1



asm0004_asm-Study 2-Results-Results2

<table>
<tr><th>Name</th><th>Type</th><th>Min</th><th>Max</th></tr>
<tr><td>Results3</td><td>Load factor</td><td>309.934
Node: 12758</td><td>2.77137e+019
Node: 11218</td></tr>
<tr><td colspan="4">
asm0004_asm-Study 2-Results-Results3</td></tr>
</table>

RESULTS TABLE

ORIGINAL MODEL

Static	Stress (N/mm^2)	Displacement (mm)	Strain
S2 Glass	9.2	2.420e-003	1.694e-006
E Glass	8.5	1.147e-008	9.234e-011

Fatigue	Damage	Load factor	Life
S2 Glass	1.001e-001	2.771e+019	1.001e+006
E Glass	1.001e-001	2.269e+024	1.001e+006

CHANGING HOLE DISTANCE

Static	Stress (N/mm^2)	Displacement (mm)	Strain
S2 Glass	8.5	1.813e-003	1.756e-006
E Glass	8.5	9.266e-003	8.973e-006

Fatigue	Damage	Load factor	Life
S2 Glass	1.001e-001	1.049e+017	1.001e+006
E Glass	1.001e+001	2.055e+016	1.001e+006

CHANGING LINK

Static	Stress (N/mm^2)	Displacement (mm)	Strain
S2 Glass	8.8	4.113e-004	1.619e-006
E Glass	8.7	8.962e-003	8.960e-006

Fatigue	Damage	Load factor	Life
S2 Glass	1.001e-001	3.442e+017	1.001e+006
E Glass	1.001e-001	9.387e+015	1.001e+006

CHANGING FIXED AREA

Static	Stress (N/mm^2)	Displacement (mm)	Strain
S2 Glass	9.6	2.200e-003	1.810e-006
E Glass	9.6	1.124e-002	9.251e-006

Fatigue	Damage	Load factor	Life
S2 Glass	1.001e-001	4.130e+018	1.001e+006
E Glass	1.001e-001	1.642e+018	1.001e+006

The results reveal that the stress and displacement values are less than their corresponding strength values. From the fatigue analysis it is understood that the damage factor is negligible for both materials and the life is about 1e^6 cycles.

CONCLUSION AND FUTURE WORK

In this paper we study the composite materials and the procedures to make such materials and analyze them. Specifically, this study focused on the structural and fatigue analysis of pinned joints. The materials used for experiments include E glass and S2 glass proxy with pinned joints contained two holes having given distance from the edges of the plates. The structural and fatigue analysis are made using Cosmos. The empirical results are made using the given details in the paper. The results reveal that the stress and displacement values are less than their corresponding strength values. The conclusion made here is that it is safe for using composite materials with respect to serial pinned joints. From the fatigue analysis it is understood that the damage factor is negligible for both materials and the life is about 1e^6 cycles. One possible direction for future work is to use alternative methodologies for the structural and fatigue analysis.

REFERENCE

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