Pin Shear –Material Testing and Validation using Finite Element Analysis (ANSYS)

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***Abstract*—A shear pin is a safety device designed to shear in the case of a mechanical overload, preventing other, more expensive parts from being damaged. As a mechanical sacrificial part, it is analogous to an electric fuse [1].**

The most common failure method for pins is through shear failure. However, there have been cases of pins failing despite being adequately sized for shear. Many users fail to take into account pin bending as a legitimate failure mode. There have been some studies done in the past to try to come up with a theoretical equation for the maximum bending stress in a pin in single and double shear. In order to come up with this equation, the pin was assumed to see a uniform load distribution [2].

In the present study, design of closing blade pin is carried out to study the shear strength of the pin material during blade off situations in aero engines. Experimental testing of pin shear was carried out; finite element analysis of pin shear phenomenon was studied using ANSYS 14.5 version. The analysis was carried out for full loading conditions for various materials such as stainless steel, aluminum and titanium. Results obtained from ANSYS were validated against experimental data and comparative details are presented.

Numerical model thus built can be used to validate the shear failure of any pin material.

Keywords—Pin Shear, Failure, Blade off, ANSYS

I. INTRODUCTION

Passing the Fan Blade Off containment test is a major milestone in the aero engine development cycle. The fan blades (not rotating) are shown in figure 1. When an engine is running there is a risk that the fan blade may break off. This event is known in the turbine industry as fan blade out or fan blade off (or FBO for short).

To fly, an engine must be certified by the Federal Aviation Administration (FAA)[9]. One milestone of the certification process is the fan blade off test. The basic idea is that the blade release should:

1. Not cause an engine fire (usually from cut fuel/oil supply lines)
2. Not fracture the cases/mounts.

The current environment for designing aircraft engine and engine-frame structural systems requires extensive levels of efforts to prepare and integrate models, generate analysis results and to post-process data. Additionally, the accuracy of the simulations is less than desired, leading to less than optimal designs, costly testing and re-designs and most important, uncertainties in factor of safety. One of the primary concerns of aircraft structure designers is the accurate simulation of the blade out event [3].

The loss of a first stage fan blade in a high bypass turbine engine can be initiated by material failure due to fatigue, crack, a bird strike or some other foreign object damage. Damage due to blade off is shown in figure 2[8].

During operation of the engine the area around the pin holes is loaded by high stresses due to the centrifugal forces coming from the rotating structures. It is very important to understand these stresses during design stage itself to ensure that they are well within the safe limit.

If the stresses generated are high (above yield strength) then the pin can fail in shear causing the blade failure and significant damage can happen for the entire engine casing itself.

In static tests of a single bolt fitting, failure of the shear pin due to bending failure will not be shown to be a factor in the failure of the lug. However, it is important to provide sufficient bending strength to ensure permanent bending deformation does not occur when subject to the limit loads so that the shear pin can be readily removed for inspection and maintenance operations.

Weakness in the shear pin can cause peaking up of non-uniform bearing loads on the lugs, influencing the lug tension and shear strength. The big unknown factor in shear pin bending is the true value of the bending moment acting on the pin because the moment arm of the resultant bearing forces is difficult to quantify [4].

In the present work the pin failure in the closing blade has been studied using material testing as well by numerically simulating the same using Finite Element Analysis (FEA) using ANSYS commercial program.

Generic FEA model has been built, which can be used to validate any material for pin subjected to single and double shear loading conditions.

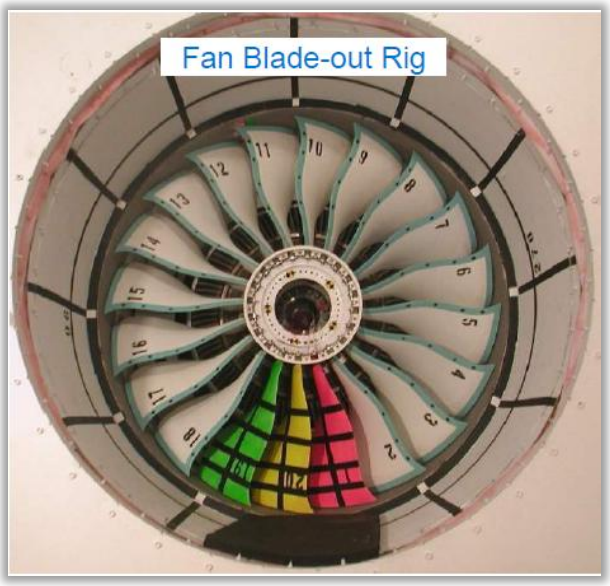

Figure: 1Fan Blade Out test Rig

Figure: 2Engine Failure seen during blade-off event

II. OBJECTIVE

The main objectives of this work include:

1. Material testing for finding the load which causes failure in pin due to shear.
2. Verification of material testing through finite element analysis.
3. Study of pin shear phenomenon for various materials using finite element analysis.
4. Comparing finite element results with material testing.
5. To ensure the finite element model is robust for single and double shear test for any material.

III. SHEAR STRENGTH TEST

The shear stress acts parallel to the plane while the tensile and compressive stress act normal to the plane. There are two main types of shear forces that can act on a structure; one is the direct or transverse shear stress which is generally observed in pin, rivets, bolts etc. The other type of shear stress is called the pure or torsional shear observed in shafts and rods.

The method of applying load to create shear is shown in figure 3.Here a cylindrical specimen is placed in the central holes of the fixed block and the load is applied to the block thereby producing a single shear.

If the specimen is extended across the gap between the two fixed blocks as shown in the figure3, it is called double shear [5].

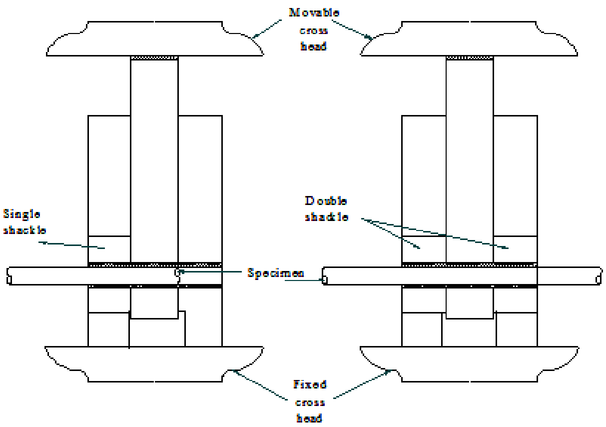

Figure: 3 Schematic of single and double Shear Test

A. MATERIAL TESTING

Testing was carried out at material testing laboratory in department of mechanical engineering Bangalore Institute of Technology, Bangalore. Figure 4 below shows the mild steel specimen used for testing.

Figure: 4Mild steel specimens used for testing

Universal testing machine was used for testing the specimen as shown in figure 5 below

Figure: 5Universal testing machine with shackles and specimen fitted

Sl. No	Material used	Type of shear	Fracture load(N) Averaged Value (3 tests)	Ultimate shear strength (N/mm^2)
1	Mild steel	Single shear	38095	337.09
2	Mild steel	Double shear	77989	345.05
3	Aluminium	Single shear	18312	162.038
4	Aluminium	Double shear	42183	186.63

Table1: Summary of the material testing values

Observation:

Material used = Mild steel
Diameter of specimen (d) = 12mm
Area of C/S, $A = \pi d^2/4$ = $113.01mm^2$

Specimen calculation:

Single shear:

Maximum shear stress τ_{max} = F/A Mpa
= 38,095 / 113.01 = 337.09 Mpa

Where F = Fracture load in (N) and A = Area of C/S of specimen in mm^2

Here the specimen calculations are shown for mild steel component and the same is repeated for aluminium also [6].

Figure: 6Fractured component pictures

IV. STRUCTURAL ANALYSIS

A. Finite Element Idealization

The material testedis a three dimensional a three dimensional geometry and hencerequires a three dimensional finite element model for numerical simulation. The complete modeling of the geometry is carried out using ANSYS Design Modeler program.

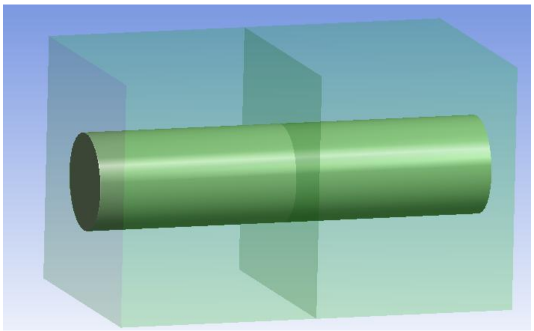

Figure: 7Assembled components

There are three components in the model; one is the pin and other two are shackles. One of the shackles is fixed and other is free to move in the axial direction.

20 Node hexahedral element (higher order) is used for generating the mesh. Mapped mesh is generated for all the three components as shown in the Figure 8 below.

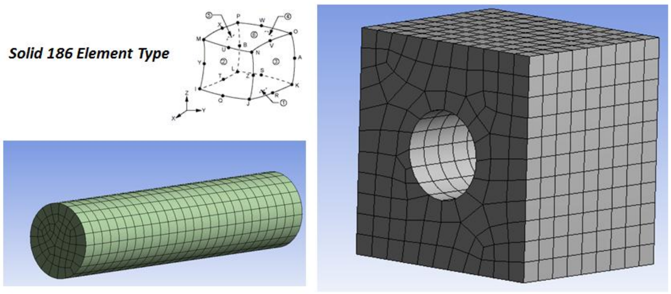

Figure: 8Finite Element Model

Since the area of interest in this study is the pin, the pin is discretized with a fine mesh and shackle with a relatively coarse mesh.

Twenty noded brick element is used to develop this Finite Element (FE) model. This element is available in finite element software ANSYS Workbench 14.5. This element being a solid has three degrees of freedom per node, namely, translation in x, y and zdirections. The finite element model of the shear test is shown in figure8.

B. Boundary conditions and loading

Frictionless contact is defined between the pin and shackles for full load transfer from shackles to pin during application of loading as shown in figure 9.

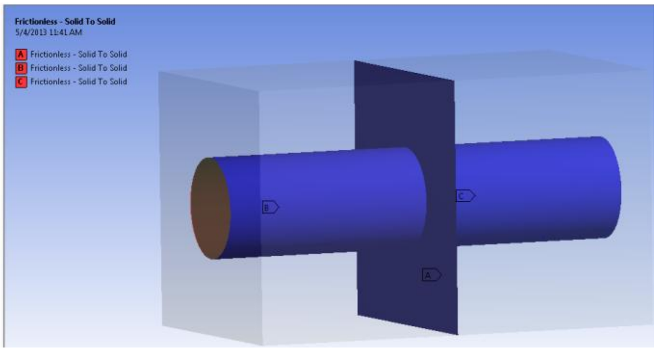

Figure: 9Frictionless contacts between pin and shackles

- The bottom of one of the shackles is completely fixed as shown in figures 10 and 11.
- The pin is fixed in X and Z direction at ends and is allowed to move in Y direction only.
- The second shackle is fixed in X and Z direction and is allowed move in Y direction only as shown in the Figure11.

  The value of force is converted into pressure and applied to the vertical face of the shackle as shown in the figures 10 and 11.

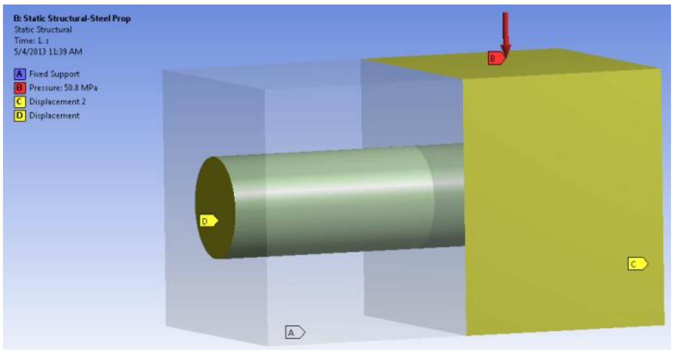

Figure: 10Loads and Boundary condition definitions

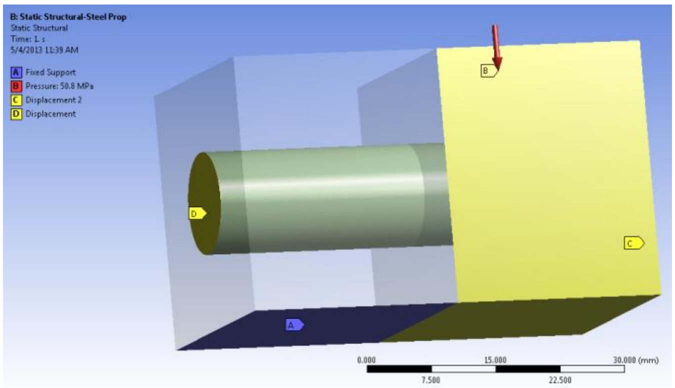

Figure: 11Loads and Boundary condition definitions

The problem was solved using ANSYS workbench Mechanical interface [7] using large displacement option.Here the loads are applied gradually and in increments. The problem was solved for three different materials and the results are presented in section vi.

V. MATERIAL PROPERTIES

Following are the material properties used in ANSYS for analysis

Mild Steel:
Young's modulus = 2E5 Mpa
Poisson's ratio = 0.3
Density = 7.85e-09 tons / mm^3

Aluminium:

Young's modulus = 71E3 Mpa
Poisson's ratio = 0.33
Density = 2.77e-09 tons / mm^3

Titanium:

Young's modulus = 96E3 Mpa
Poisson's ratio = 0.29
Density = 4.62e-09 tons / mm^3

VI. RESULT AND DISCUSSION

Figure12 shows the total deformation of the entire assembly. Since the area of interest is the pin, the results are plotted specificallyfor the pin component

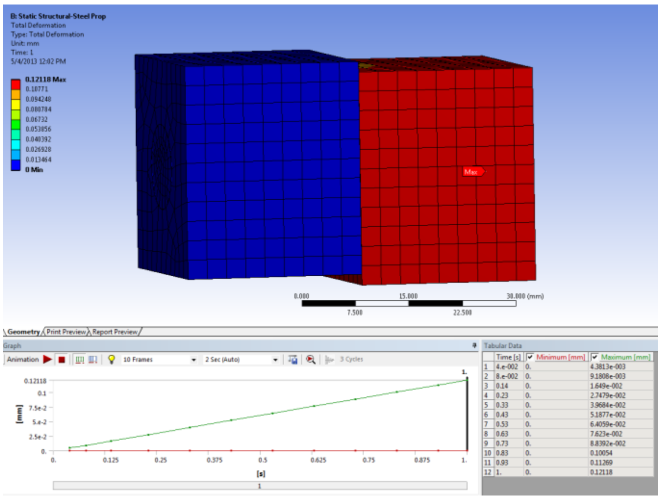

Figure: 12Deformation plot

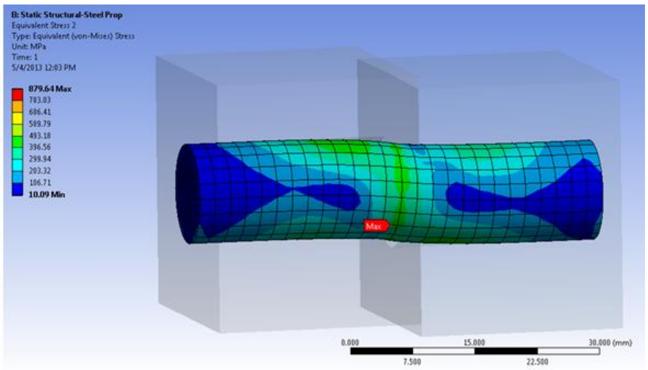

Figure: 13Equivalent Von-Mises Stress

Maximum von Mises stress is reported at the pin shear region as shown in figure 13

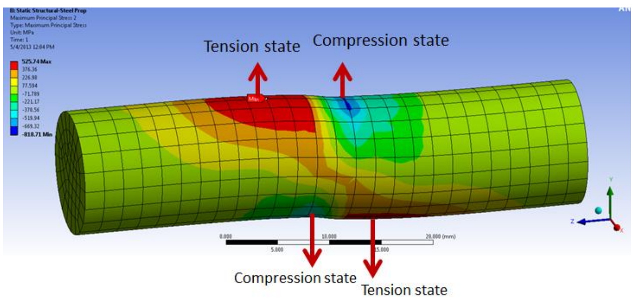

Figure: 14Principal Stress plot

The above figure 14 clearly shows that one side of pin (loaded side) is in compression state and the other side of the pin is in tension state.

Since the entire area of cross section of the pin experiences the load, we need to find the average shear stresses at the point where the specimen gets sheared.

ANSYS default does not display averaged stress values; to do this a small macro is developed using ANSYS commands for extracting the results in ANSYS postprocessor. Contour plot of the average shear stress is as shown in figure 16.

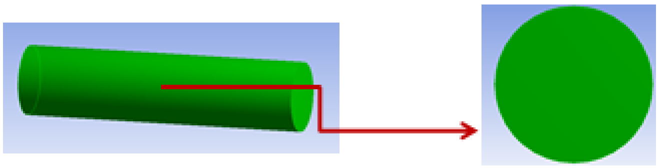

Figure: 15 Average area for shear stress calculations

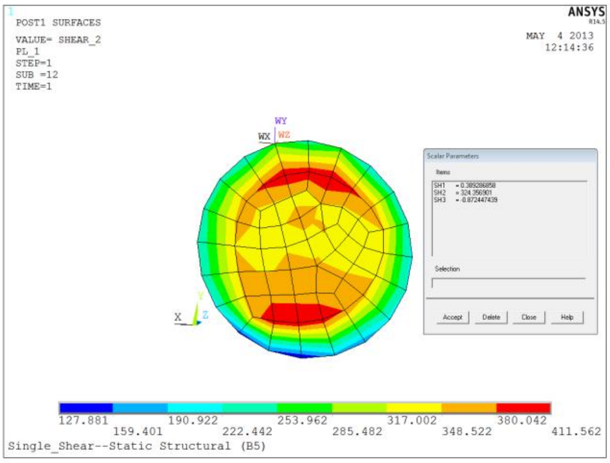

Figure: 16 Average shear stress calculations for Mild Steel

The procedure described here was carried out for mild steel and aluminum materials. Since the Titanium material was not available for testing, hand calculations were performed for this material to obtain the average shear stress value.

Specimen	Average Shear Stress in N/mm^2 from material testing	Average Shear Stress in N/mm^2 From ANSYS
Mild Steel	337	324
Aluminum	162	156
TI-6Al-4V	562	558

Table 2: Summary of the material testing and FEA results for Single Shear

Table 2 shows the results of average shear stress from material testing as compared to the results from ANSYS. For the single shear case. Data from test compare well with the analysis.

Specimen	Average Shear Stress in N/mm^2 from material testing	Average Shear Stress in N/mm^2 From ANSYS
Mild Steel	345	332
Aluminum	186	169
TI-6Al-4V	562	550

Table 3: Summary of the material testing and FEA results for Double Shear

Table 3 shows the comparison of test against analysis for the double shear case. Again data from test confirms well with the analysis.

VII. Conclusions:

In this paper a methodology for assessingpin shear failure using finite element analysis is presented.

- FEA methodology has been established for shear testing using ANSYS Program.
- Results obtained from ANSYS matchedwell with the experimental data as tabulated in table 3.
- The procedure described can be extended for predicting the failure of similar structural elements using ANSYS program.

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