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Design Optimization and Analysis of Light Weight Sandwich Honeycomb Panels for Aircraft Applications

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Abstract: *We humans, are always on the trail of inventions and innovations. The innovations cause the trail to increase within the advancement of materials. The advancement causes the path to expanding inside the progression of materials. Progression of material is essentials for boosting the fuel economy of modern aircraft and also maintaining safety and performance. Since it takes less capacity to hasten a lighter object than a heavier one. A 10% reduction in aircraft weight can result in a 6%-8% fuel economy enhancement. The reduction of weight will increase in the development of the overall performance of aircraft and in saving the fuel. The movement of aircraft is through the air, so we need the material to be lightweight and good strength ratio also. Honeycomb materials have been developed to resist the high temperature and also have good resistance to fatigue strength. Honeycomb sandwich panels are orthotropic which implies they grow in longitudinal, radial, and tangential directions. In this article, we compared the aluminum honeycomb core with the Hastelloy X honeycomb core. The sandwich is a composite structure, the materials are orthotropic, and the core shear modulus is low; therefore, the shear deformations must be checked. So, the design of the sandwich composite structure was done in Catia software, and analysis was done in ANSYS software. The composite sandwich panel was tested on three conditions (I) uniform pressure application (II) One End Fixed (III) Both the Ends Fixed. Based on the results we conclude that Hastelloy X has good stress factor, fatigue strength life cycle, and good thermal resistance when compared with aluminum.*

1. Introduction

Material Technology is an advancing innovation that constantly increases modern materials with properties that leads to modern applications. A nickel-based superalloy is a strong metal and highly corrosive resistant. In the rapid increase of technology, new advancing materials are getting developed which are lightweight and highly corrosive resistant. Hastelloy X is one of them and it is a nickel-based superalloy that is used in the aircraft application. Hastelloy x is used in the honeycomb structure as a form of seals in the aircraft. As the Hastelloy X metal is lightweight and corrosive resistant, so it is used in the application of aircraft. Aluminum is also one of the finest metals which is lightweight and used mostly in automobile applications. The basic reason for using the honeycomb structure is to save weight, however, smooth skins and excellent fatigue resistance are also attributes of the honeycomb panel. But honeycomb used in the sandwich composite beams gives more bending stiffness and strength that is combined with low weight [1][15]. The concept of sandwich composite structure will increment the range of merged functions such as thermal and sound insulation, excellent features like fire safety, good energy absorption, directional properties of face sheets enabling optimized design, and production of complex and smooth hydrodynamic surfaces [2][3][5][18]. M.N.F Saniman[10] M.Sugaraneswaran [11] Z.Hryciow [12] has used honeycomb structure for comparing it with other conventional geometry designs to validate the surface area is more than the honeycomb.

Mokhtar [6] made a honeycomb bending analysis on the symmetrically laminated plates on the composite solid element using ANSYS. He used the shell 99 and shell 46 elements and did the deflection and von misses stress analysis. He concluded that stress is induced due to the effect of stacking. Both Ganesh [7] did the structural analysis on honeycomb panels of 100mm x 100mm choosing three different materials (Aluminium alloy, steel & Titanium). He concluded that aluminum is best when compared with others in the Strength weight ratio. Shaik Nazeer [8] analyzed comparing between the aluminum and titanium honeycomb using ANSYS. He concluded that the cost of titanium is very high so the use of aluminum which is low cost and good strength can be considered as the best. Dr.Flora Jessica[9] has made a pressure analysis on the aluminum and titanium honeycomb core using ANSYS.

W.miller and Aspron D has stated the importance of buckling load resistance and explores the buckling behavior of the honeycomb structure[13][14]. Crupi has studied the mechanical behavior of honeycomb structure under bending and impact loading and concluded that the strength increases with GFRP outer skins which are designed for sandwich applications[16]. Adams has investigated the damped analysis of aluminum and Nomex honeycomb material and concluded the shear moduli are similar for both the materials.[17][19]. M.Gotoh studied the crush behaviour of honeycomb cell shape and the foil thickness by using numerical simulation[20]. Muhammad Kashif khan has compared the material properties between aluminium facing honeycomb panel and glass fibre facing honeycomb panel. He also studied

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the bonding strength of the face joint and core joint[21].Ahamed abbabi studied the analysis of honeycomb structure using 4 points bending stress on the honeycomb sandwich panel[22]. Pauilus studied the deformation analysis on honeycomb core using quasi-static and dynamic loading factors[23].k.kantha rao made the experimental analysis on the comparison of aluminium rod and aluminium honeycomb core[24].

2 Experimental Procedure

(i) **Design Methodology:** The first stage or preliminary level of design is to create a simple hexagonal cell structure using CATIA software design tools. After the design of the hexagonal cell, we need to assemble the group of hexagonal cells to a certain length to form a flat honeycomb structure. Now the second stage of the design is to create a rectangular plate for the honeycomb structure so that it looks like a sandwich panel.

(ii) **Problem Definition:** To perform an accurate analysis an engineer must determine some information such as structural loads, geometry, support conditions, and material properties. The result of such analysis typically includes deformation, stress, and displacement. This information is then compared to criteria that indicate the condition of failure.

(iii) **Material Selection:** Once the design phase in CATIA is completed then we convert the CATIA file to IGES format so that the design file can be accessed in any analysis applications such as ANSYS, NX, SOLID EDGE, SOLID WORKS, etc. The design file is opened in the ANSYS software and in the material section, selection of materials like aluminium and Hastelloy X are selected.

3. Modelling Phase

In the modeling phase, we used CATIA software as it delivers the unique ability not only to model any product but to do so in the context of its real-life behavior: design in the age of experience.

3.1.1 Modelling of Hexagonal honeycomb structure

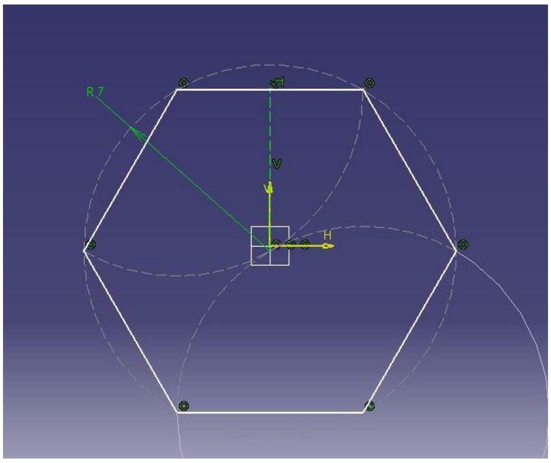


Fig 3.1 Hexagonal cell

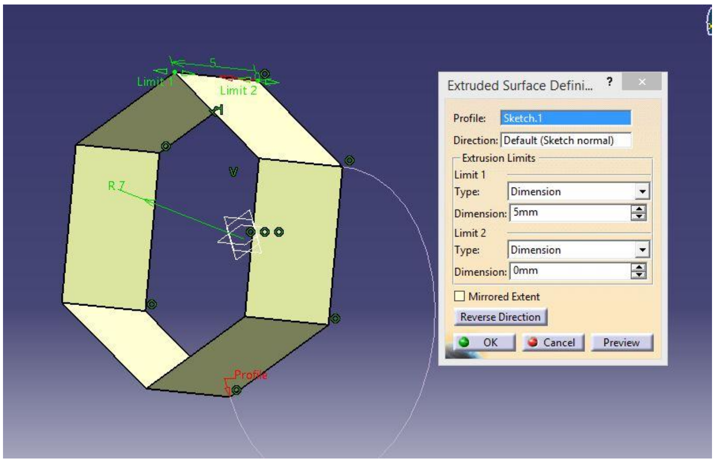


Fig 3.2 Extruded Hexagonal cell

Dimensions of Hexagonal Cell

- Edge Length = 3.5mm
- Radius = 7mm
- Thickness = 0.5mm

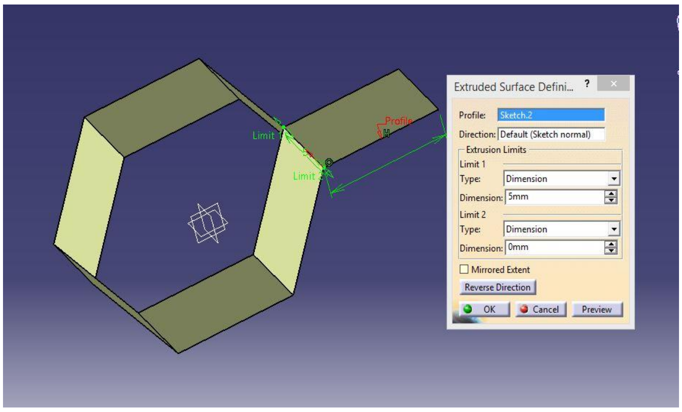


Fig 3.3 Creating offset for pattern design

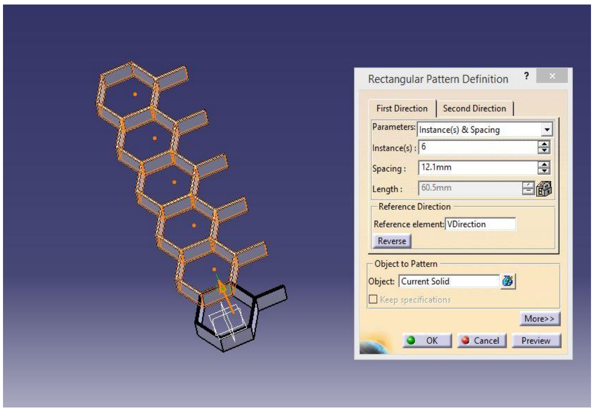


Fig 3.4 Rectangular pattern of hexagonal cell in V-Direction

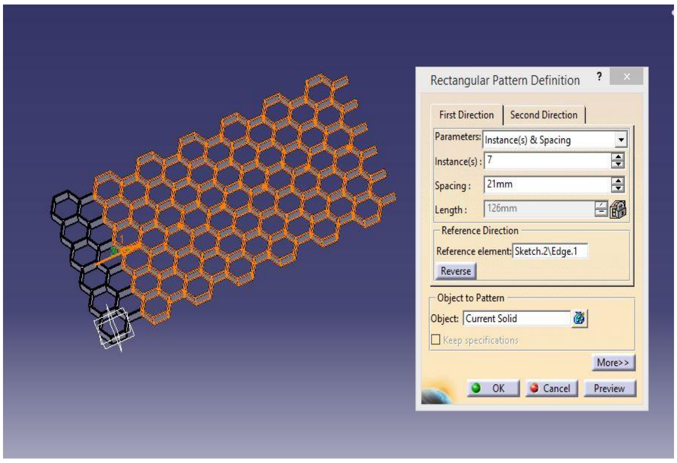


Fig 3.5 Rectangular pattern of hexagonal cell in H-Direction

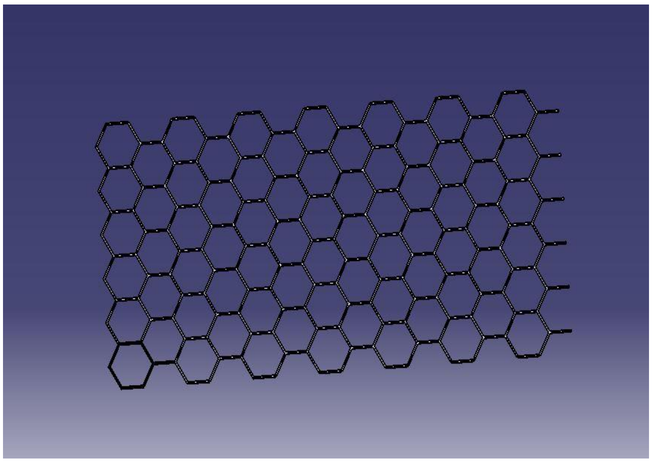


Fig 3.6 Hexagonal Honeycomb Structure

Modeling of Rectangular Plate

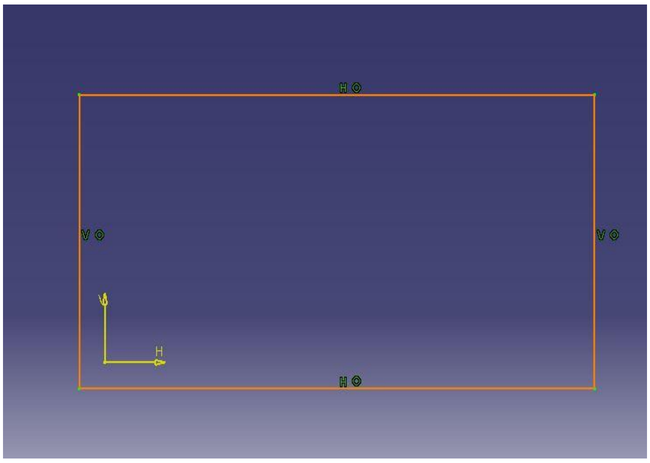


Fig 3.7 Rectangular Plate

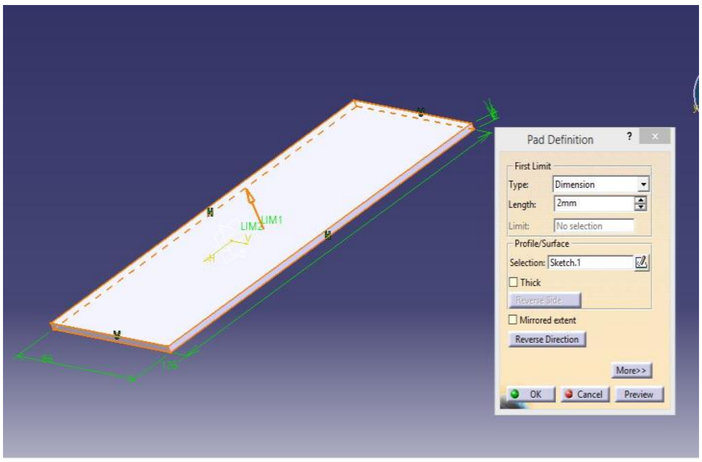


Fig 3.8 Pad definition on Rectangular Plate

Dimensions of Rectangular Plate

- Length = 140mm
- Width = 70mm
- Thickness = 2mm

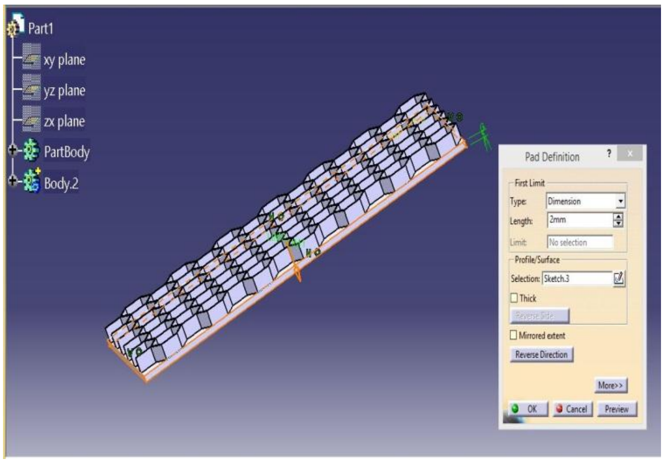


Fig 3.9 Rectangular Plate as Bottom face sheet

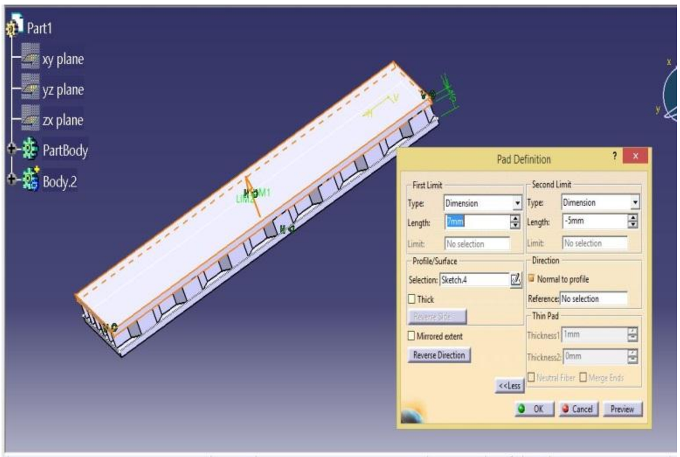


Fig 3.10 Rectangular Plate as Top face sheet

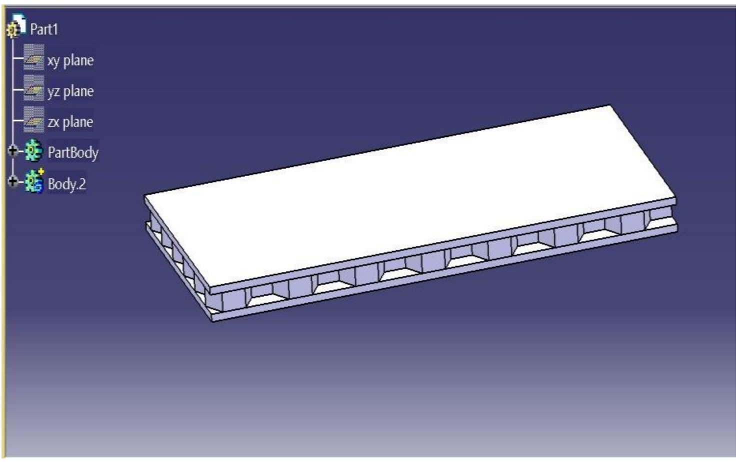


Fig 3.11 Sandwich Honeycomb Structure

Ansys Analysis

ANSYS is engineering simulation software Dr. John A. Swanson has been developed Swanson Analysis System, Inc. (SASI) in 1970. Its main was to improve and advertise fixed component analysis software for essential behaviour of structure that could stimulate Static (stationary), Dynamic (moving), and thermal (heat transfer) problems.

4. Result and Discussions

The Structural analysis done by the following cases, in each case consider deformation, stress, and strain.

4.1 Case 1: Pressure

In this case, one end of the composite material is fixed and the pressure is applied on the other end. By this experiment we can get the total deformation, von misses stress that is developed in the composite materials.

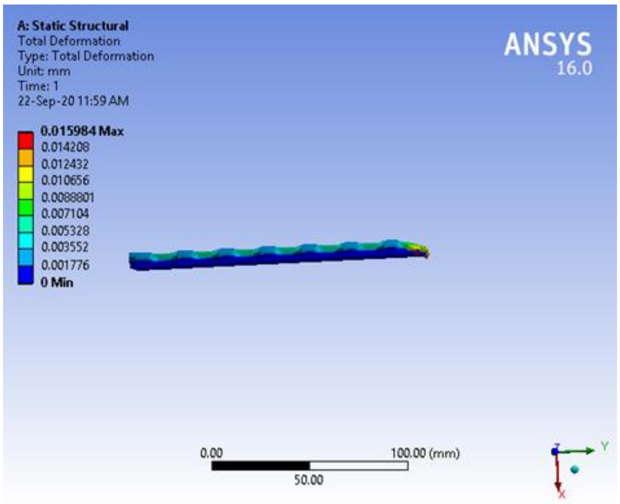


Fig 4.1.1 Total deformation of aluminium

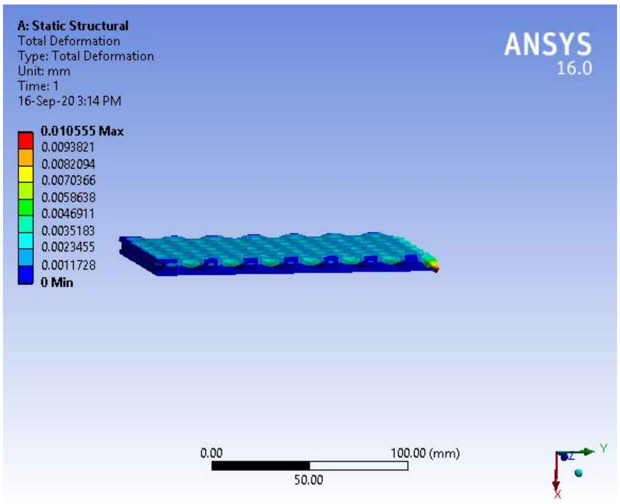


Fig 4.1.2 Total deformation of Hastelloy -X

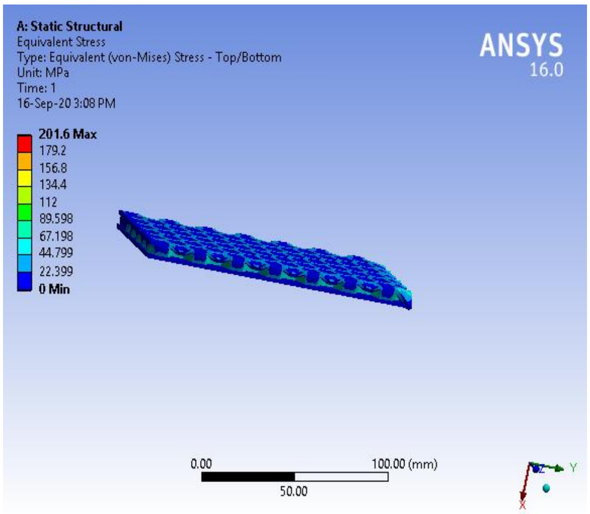


Fig 4.1.3 Von misses stress of aluminium

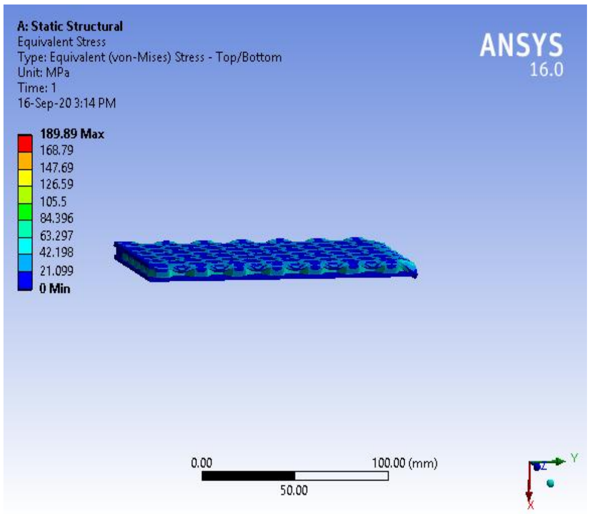


Fig 4.1.4 Von misses stress of Hastelloy X

Results: From the above analysis we can say that the stress that is developed in Hastelloy X is very less when compared to the aluminium. It states that the Hastelloy X absorbs less pressure which gives more life to the component.

Table 1 Values of case – I

Case 1	Total Deformation	Von-Mises Stress
Aluminium	0.01598 mm	201.6 Mpa
Hastelloy x	0.01055 mm	189.89 Mpa

4.2 Case II: One End Fixed (Cantilever Beam)

In this case, we fix the one side length as a cantilever beam, and uniform load is applied on the free end. We can find the deformation and stress-induced on the beam.

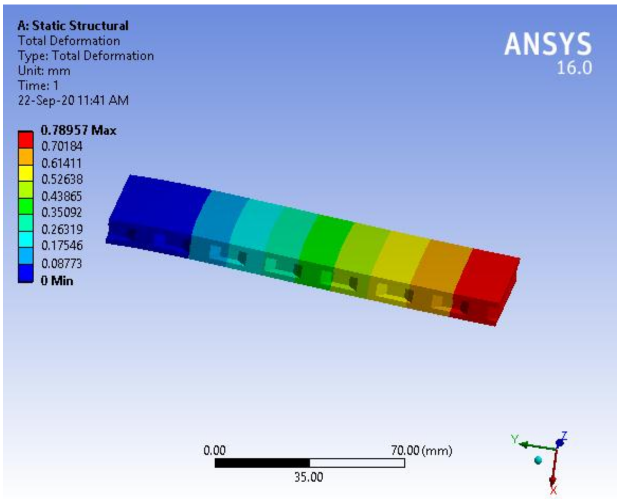
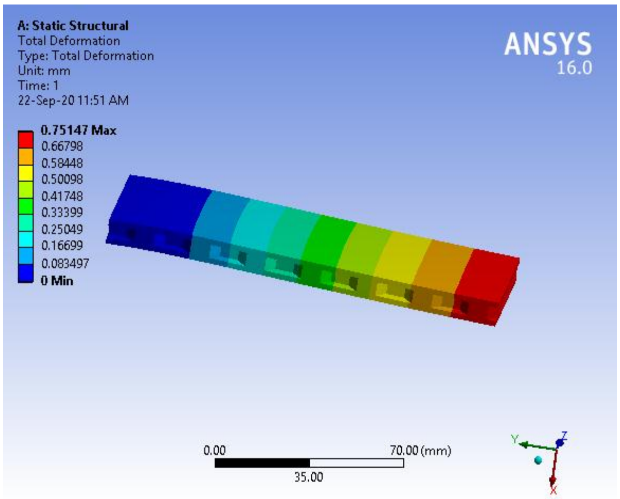


Fig 4.2.1 Total deformation of aluminium



4.2.2 Total deformation of Hastelloy -X

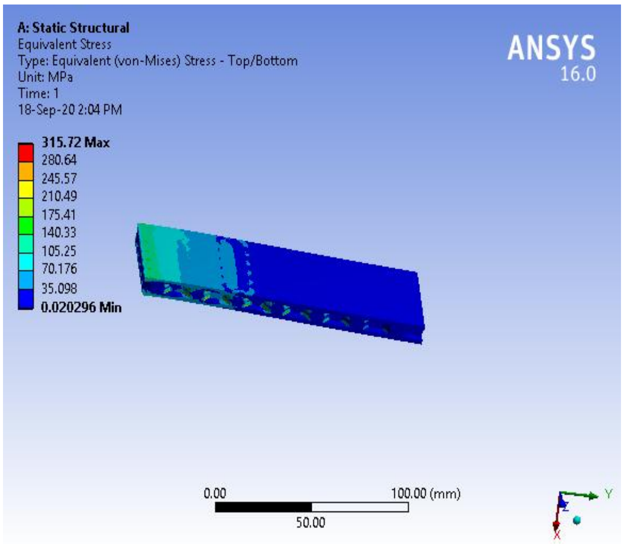


Fig 4.2.1 Von misses stress of aluminium

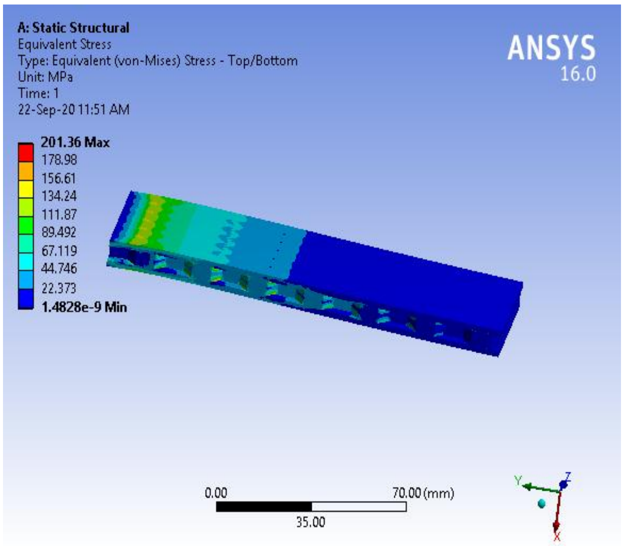


Fig 4.2.2 Von misses stress of Hastelloy X

Results: From the above analysis we can state that the Hastelloy -X has less deflection when compared to the aluminium.

Table 2 Values of Case – II

Case 2	Total Deformation	Von-Mises Stress
Aluminium	0.78957 mm	315.72 mpa
Hastelloy x	0.75147 mm	201.36 mpa

4.3 Case III: Both the Ends Fixed

In this case, we fix both the side length of the component and subject the load at the center. Complete stress is induced at the center.

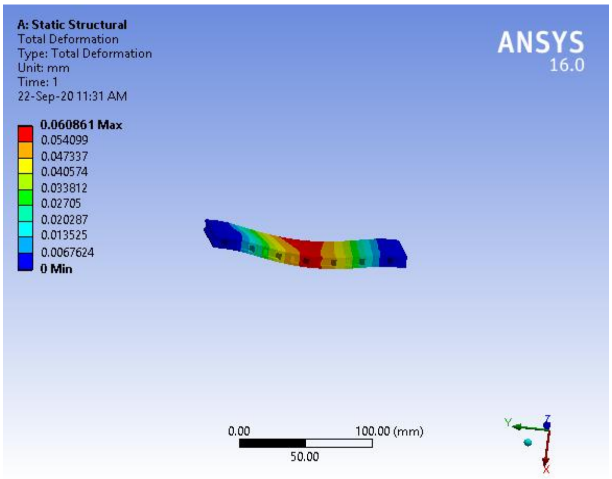


Fig 4.3.1 Total deformation of Aluminium

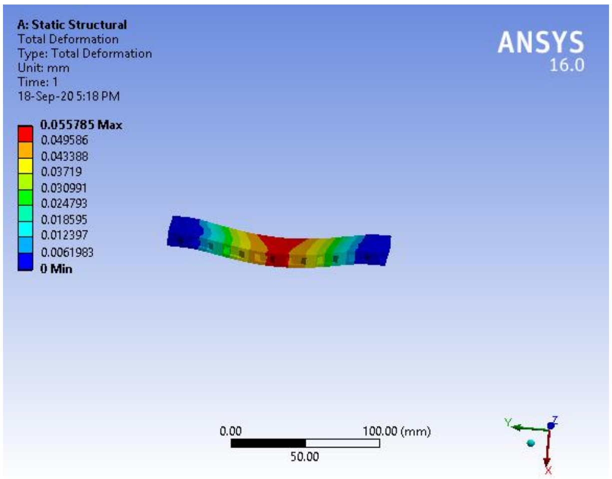


Fig 4.3.2 Total deformation of Hastelloy X

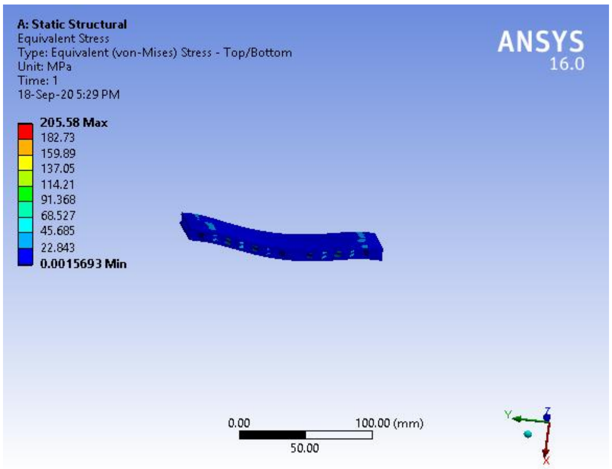


Fig 4.3.3 Von misses stress of Aluminium

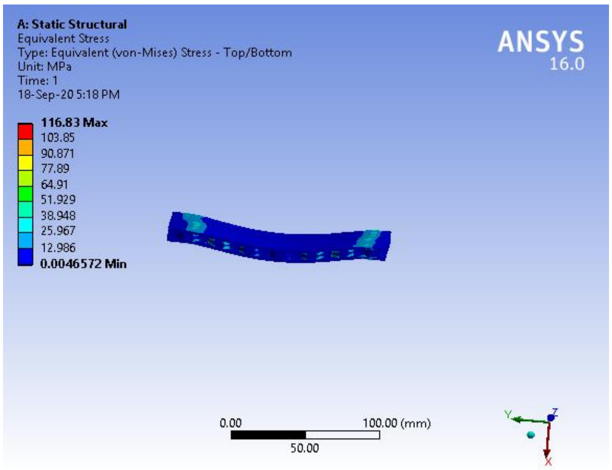


Fig 4.3.4 Von misses stress of Hastelloy X

Results: From the above analysis we can state that the Maximum deflection has taken place at the center of the beam and the Hastelloy X has less value compared to the Aluminium.

Table 3 Values of Case – III

Case 3	Total Deformation	Von-Mises Stress
Aluminium	0.060861 mm	205.58 mpa
Hastelloy x	0.055785 mm	116.83 mpa

4.4 Fatigue Analysis

The material strength cannot be decided through a single static load. Material strength will be known when it is subjected to repeated variations in the load. The Phenomenon of decreasing the strength of the material is known as fatigue. A fatigue failure begins with a small crack. To do the fatigue analysis we must take one condition from the above case and apply the fatigue analysis to it. Here we consider the first case and apply the fatigue analysis to it.

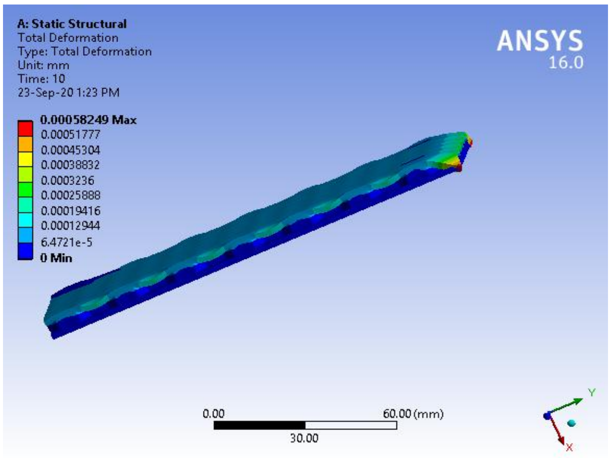


Fig 4.4.1 Total deformation of aluminium

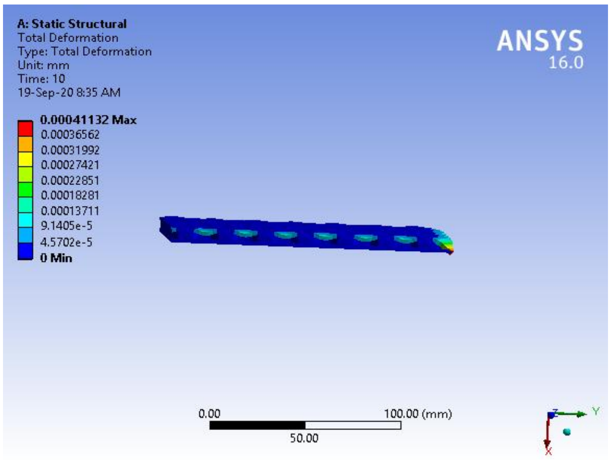


Fig 4.4.2 Total deformation of Hastelloy –X

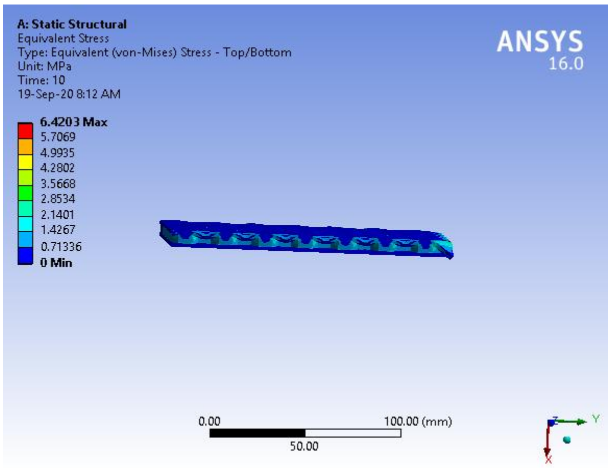


Fig 4.4.3 Von misses stress of aluminium

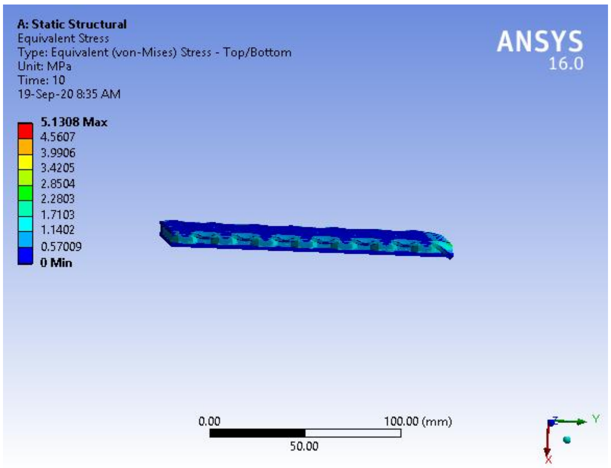


Fig 4.4.4 Von misses stress of Hastelloy X

Results: From the fatigue analysis we can say that Hastelloy X has more strength when compared with aluminum. Hastelloy X has survived a greater number of load cycles when compared with Aluminium. The Graph of Stress to the number of cycles for different alternating stress ratio is given below.

Graphs for Aluminium Al3003

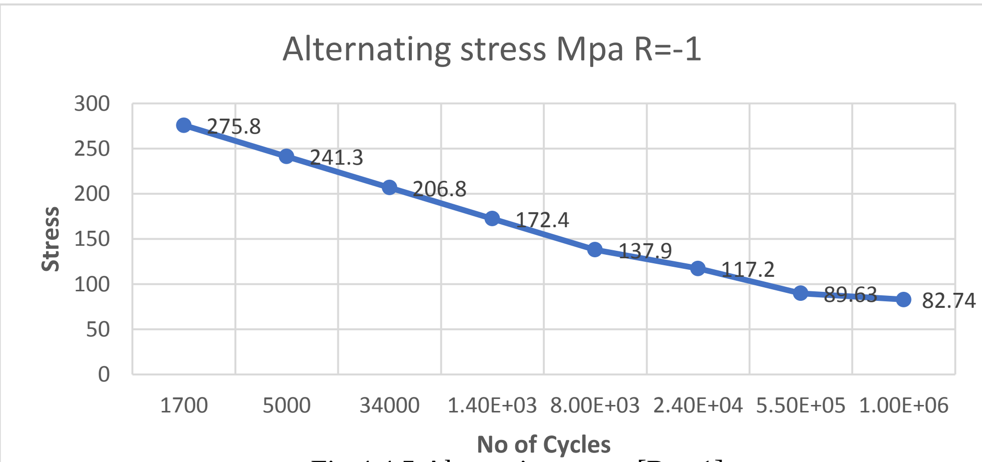


Fig 4.4.5 Alternating stress [R= -1]

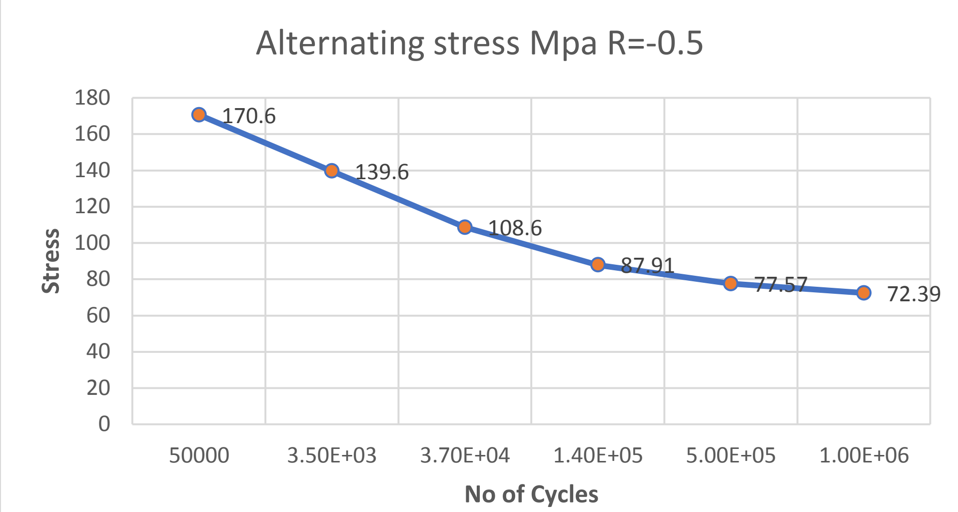


Fig 4.4.6 Alternating stress [R= -0.5]

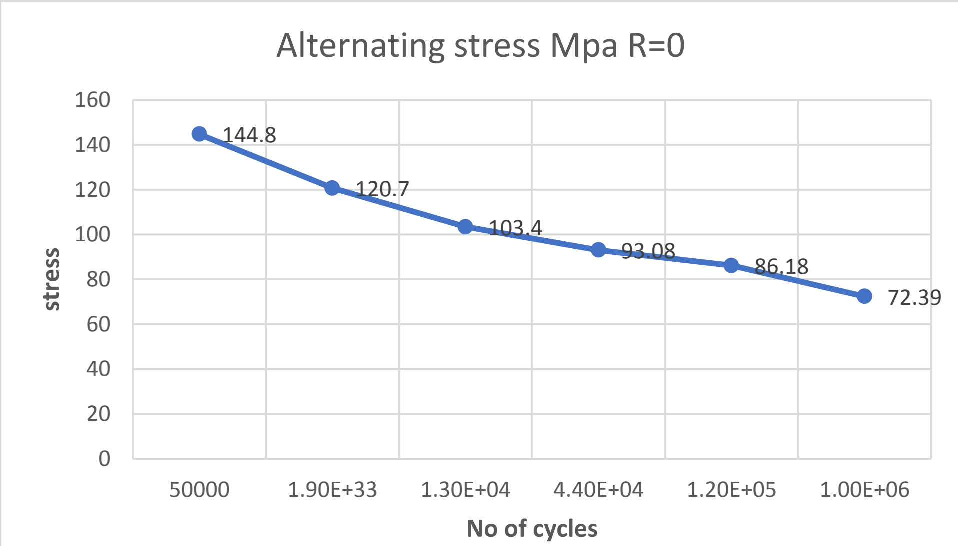


Fig 4.4.7 Alternating stress [R= 0]

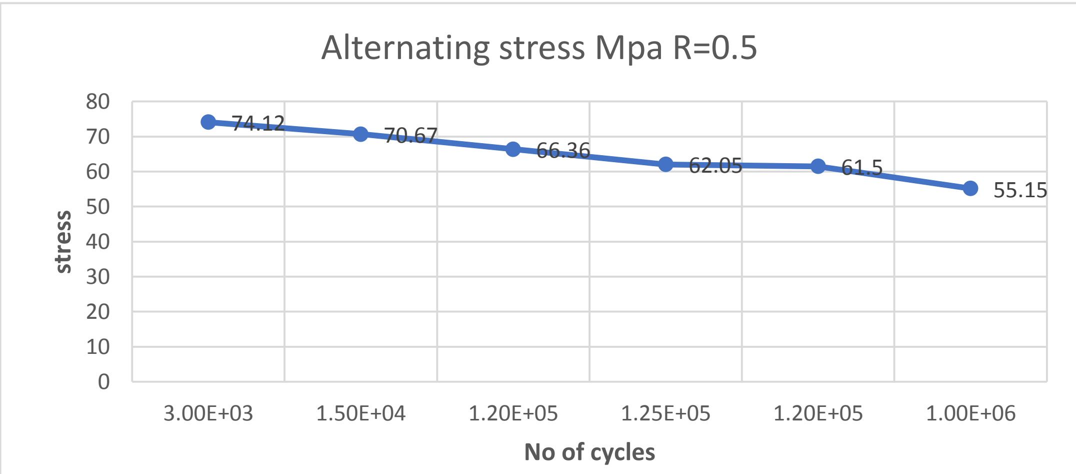


Fig 4.4.8 Alternating stress [R= 0.5]

Graphs for Hastelloy – X

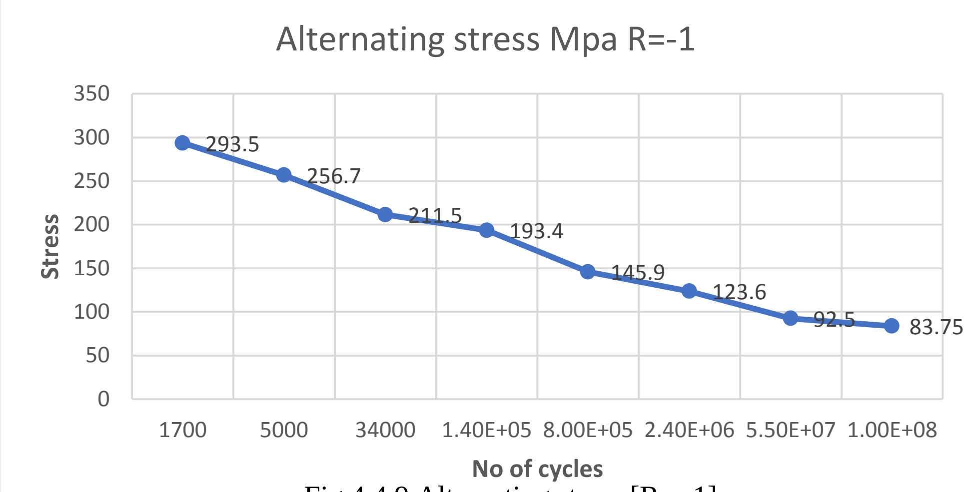


Fig 4.4.9 Alternating stress [R= -1]

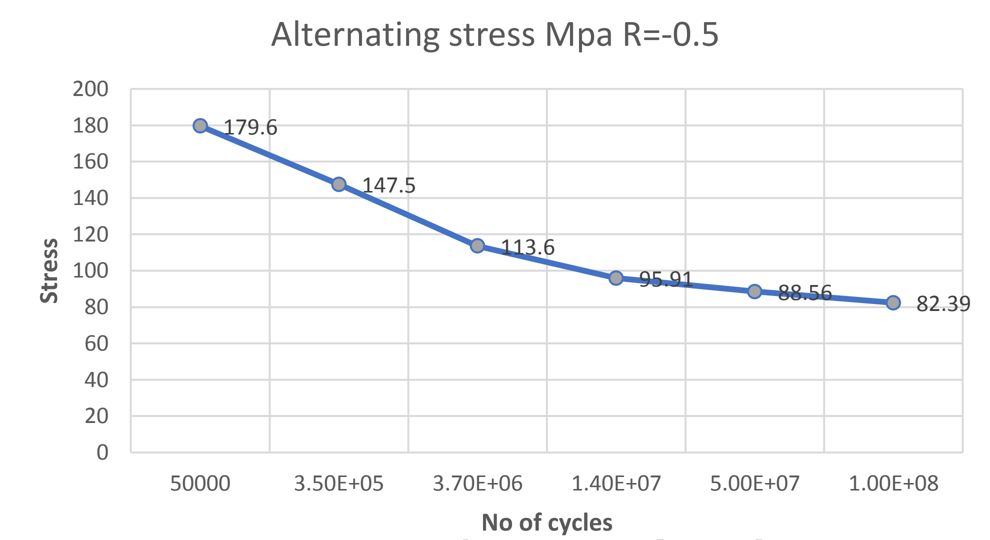


Fig 4.4.10 Alternating stress [R= -0.5]

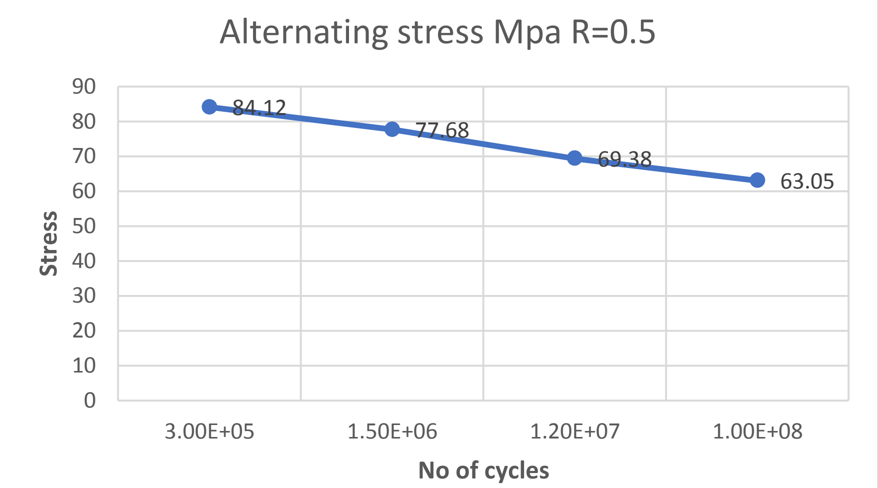


Fig 4.4.11 Alternating stress [R= 0.5]

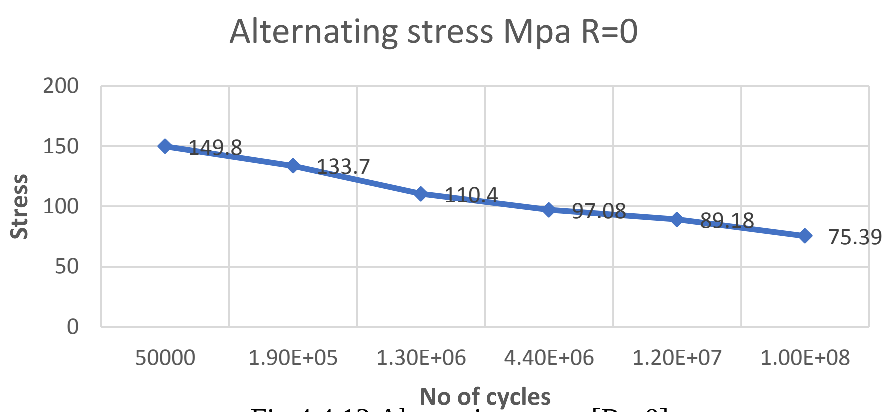


Fig 4.4.12 Alternating stress [R= 0]

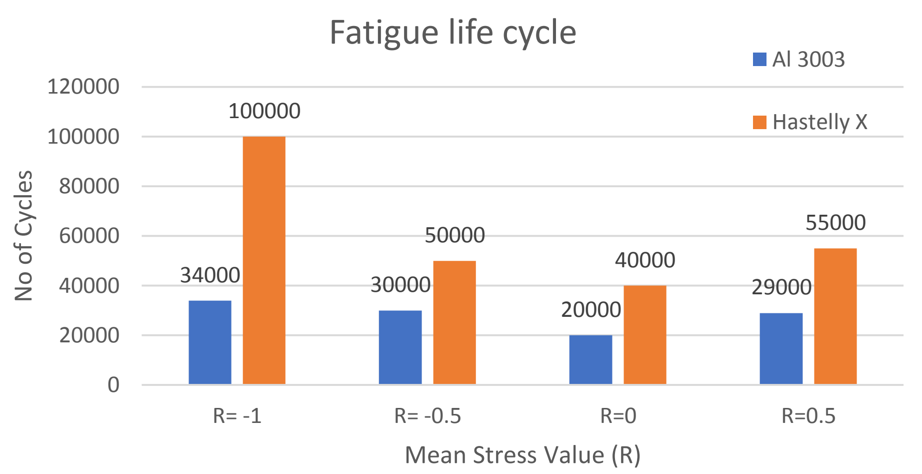


Fig 4.4.13 Fatigue life cycle comparison

Table 4 Values of Fatigue Analysis

	AL3003	**Hastelloy X**
Total Deformation	0.0005823 mm	6.420 mm
Von misses stress	0.0004113 mpa	5.1308 mpa
Fatigue life	1.e+006 cycles	1.e+008 cycles
Safety factor	13.426	>15

4.5 Thermal Analysis

The basis for thermal analysis in ANSYS is a heat balance equation obtained from the principle of conservation of energy. The finite element solution you perform via Mechanical APDL calculates nodal temperatures, then uses the nodal temperatures to obtain other thermal quantities.

In this experiment, we did the transient thermal analysis on Al3003 and Hastelloy-X to find the heat flux that developed over a period of time.

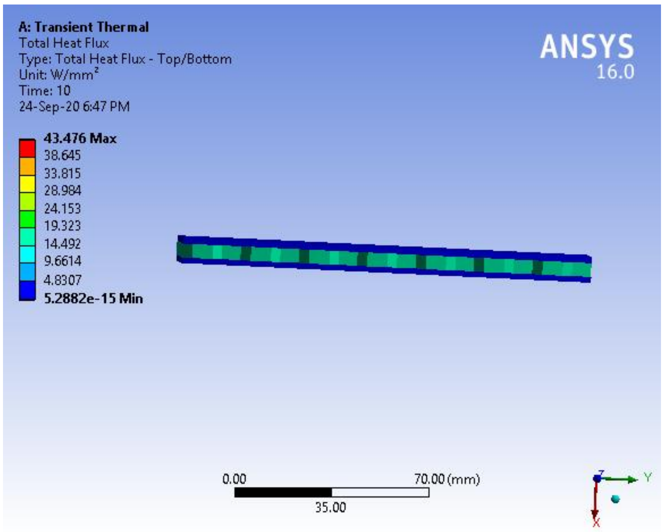


Fig 4.5.1 Heat Flux of Aluminium

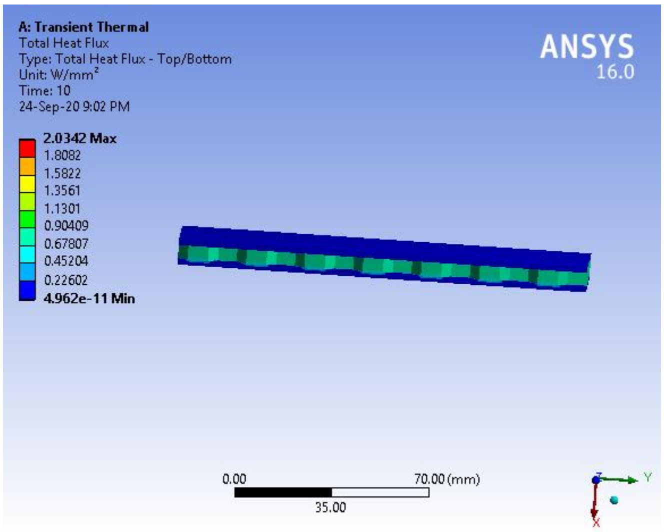


Fig 4.5.2 Heat Flux of Hastelloy X

Results: The heat flux induced more on the Al3003 when compared with Hastelloy X. The temperature was increased up to 500 °C and maintained a minimum of 20°C. The heat flux helps to evaluate heat transfer performance such as thermal protection, metal Heat treatment, etc. As it states clearly that aluminum has more heat absorption when compared with Hastelloy X.

Table 5 Values of ANSYS Thermal Analysis

Ansys value	Heat Flux
Aluminum	43.47 W/mm -k °C
Hastelloy X	2.0342 W/mm -k °C

Theoretical Analysis

Since Heat transfer through the wall is done by conduction, the heat flux may be determined from Fourier's law. Using the equation, we have

$Q_x = -kA\frac{\Delta T}{L}$ ----------------- (1)

Q=Heat flow through a body per unit time

A= surface area of heat flow

ΔT = Temperature difference of the faces of a block of thickness

L=thickness of the plate

Analysis:

Since heat transfer through the wall is by conduction, the heat flux may be determined from Fourier's law.

Area = length x breath x Height

= 140mm x 70mm x 9mm

= 88,200 mm

For Aluminium

Thermal conductivity = 154 W/m-k °C

Temperature T_1 = 500°C

T_2 = 22°C

Using Equation 1

$Q_x = -kA\frac{\Delta T}{L}$

= - 154 x 88,200 x ((500°C -22°C)/140)

= 1,35,828 x 3.41428

= 46.3754 x 10^6 W/mm -k° C

For Hastelloy X

Thermal conductivity = 9.1 W/m-k° C

Q_x = -9.1 x 88,200 x (-3.41428)

= 2.740 x 10^6 W/mm -k° C

Table 6 Values of Theoretical Thermal Analysis

Theoretical Value	Heat Flux
Aluminum	46.375 W/mm -k° C
Hastelloy X	2.740 W/mm – k °C

Conclusion

Honeycomb structure has good strength with minimum compression and minimum deformation rate. Based on the ANSYS results we can say that Hastelloy X has a good working condition at high temperatures with a low corrosive rate when compared with aluminum. Whereas aluminum has less heat flux which can not be used at high-temperature conditions. Now a day to attain high efficiency in aerospace and aircraft applications the material should resist high-temperature conditions and should have good fatigue resistance also. From the above properties, we can state that the Hastelloy x is suitable for aircraft and aerospace applications as it is strong and good heat resistance.

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