Design And Structural Analysis Of An Aircraft Wing By Using Aluminium Silicon Carbide Composite Materials

K. Sruthi, T. Lakshmana Kishore, M. Komaleswara Rao
[1]M.Tech student, [2]Assistant professor, [3]Assistant professor(contract)
Mechanical Engineering (Machine Design), Jntuk-University College of Engineering Vizianagaram, India

---

Abstract - This paper deals with the reduction of weight ratio in the wing structure improves the efficiency and performance of an aircraft wing. Amongst all the aircraft parts reduction in the weight of the wing has got higher importance. Generally an aircraft wing structures are design using pure aluminium, but in this project composite material which is a combination of Aluminium LM25 (AL) and Silicon Carbide (SiC) where in aluminium is the base metal and silicon carbide is reinforcement is used to reduce the weight ratio of the wing structure. By varying silicon carbide percentages in aluminium25 four types of specimens are prepared using stir casting process. The young's modulus, Poisson's ratio and density of each specimen are determined experimentally by subjecting the specimen to compression test, hardness test and tensile test. By comparing the material properties obtained experimentally optimum percentage of silicon carbide in aluminium is determined. A suitable wing profile NACA 4412 is selected and modelled in CATIAV5 R20. The generated wing profile is imported to ANSYS WORKBENCH. Static structural analysis is carried out in ANSYS by inputting the properties of the optimum specimen which are obtained experimentally. Similarly by in putting pure AL25 properties. The results obtained from ANSYS for pure AL25 and metal matrix composite (SiC) are compared. By comparing the results it is found that composite material has better material properties and stresses than pure aluminium.

Keywords - Aircraft wing, Aluminium alloy (LM25), Silicon Carbide(SiC), stir casting, CATIA, ANSYS workbench.

I.INTRODUCTION

The design and manufacture of aircraft wings require attention to several unique structural demands. High strength and light weight are the two primary functional requirements to be considered in selecting materials for the construction of aircraft wing. Traditionally aero planes have been made out of metal like alloys of aluminium. Now a days the silicon carbide metal matrix composites have replaced the traditional metals, to make an aircraft lighter with added benefits of less maintenance, super fatigue resistance and high fuel efficiency. These composite materials can provide a much higher strength to weight ratio and stiffness-to-weight ratio than metals. In order to study the structural behaviour of a wing the linear static analysis is carried out on an aircraft wing and the stresses and displacements are analysed. The objective of this study includes structural idealization, Finite element modelling using ANSYS 15, linear static analysis results.

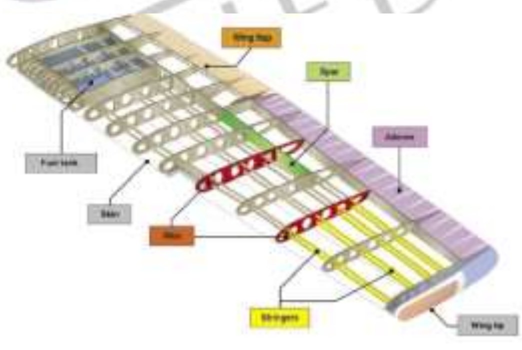


Figure .1: Aircraft Wing

Daniel P Raymer[1] has described the various aerodynamic considerations in the design of aircrafts. According to him the key geometric parameters of wing are span, reference wing area, aspect ratio and taper ratio.

Dr. M. Neubauer[2], G. Gunther[3] gave description regarding various loads to be considered in the analysis and design of air frame structures .He also discussed the Conversion of "external loads" into structural airframe loads. He conducted aircraft analysis using static loads and fatigue loads.

Sanya Maria Gomez[4] has analysed wing components like ribs, spars and panels of hypersonic aircraft using FEM considering both isotropic and composite materials. The optimum ply orientation was obtained by conducting parametric study using ANSYS FEM package by varying the orientation sequence in the composites.

Dr.R.Rajappan[5], V.Pugazhenti[6] in their thesis deals with bending Finite Element Analysis of monocoque laminated composite aircraft (subsonic and supersonic) wing using commercial software ANSYS.

II.MATERIALS AND STIR CASTING PROCEDURE

2.1 Materials

In this work for preparing metal matrix composites, aluminium alloy (LM 25) is used as base material, silicon carbide in powder form are used as the reinforcement. Silicon carbide having mesh size (30µm), aluminium alloy ingot is cut into small pieces of 1kg, so that it can easily place in graphite crucible for melting.

Aluminium alloy (LM 25)

The tensile properties of aluminium alloy at elevated temperatures are influenced by the condition (heat treatment) of the castings and the duration at the elevated temperatures. The heat treated alloy has fairly good machining properties. They are of high resistance to corrosive attack by sea water and marine atmospheres.

Silicon Carbide (SiC)

Silicon carbide is one of the most promising ceramic materials due to its attractive properties, including high strength, high density, extremely high hardness, good chemical stability and neutron absorption capability. Silicon carbide has stability to ionizing radiation. It has toughness similar to diamond. It is difficult to sinter to high relative densities without the use of sintering aids. It has good nuclear properties.

2.2 Fabrication Procedure

The schematic diagram of stir casting for production of metal matrix composite shown in figure 2. Stir casting is a primary process of composite production in which continuous stirring of molten base metal is done followed by introduction of reinforcements. The resulting mixture is poured into the die and allowed to solidify. In stir casting, the particles often tend to form specimens, which can be only dissolved by vigorous stirring at high temperature. The various advantages of stir casting are simplicity, flexibility, applicability to large quantity, near net shaping, lower cost of processing and easier control of matrix structure. In this work stir casting method is used for preparing aluminium metal matrix composite. This whirlpool technique provides high strength and homogeneous set of aluminium composite materials.

Figure.2: Stir casting Furnace

The fabrication of LM25 Al-SiC composites were carried out by stir casting process. Silicon carbide powder was preheated at around 800^0c for 2 hrs to make their surfaces oxidized. LM25 Al alloy ingots were taken into a graphite crucible and melted in a stir casting furnace. They were then slightly cooled to below the liquids, to maintain the slurry in the semi-solid state. The preheated silicon carbide powder were added and mixed manually. The composite slurry was then reheated to a fully liquid state and mechanical mixing was carried out about 20 min at an average mixing speed of 200 rpm. The final temperature was controlled to be around 750^0c. After through stirring the melt was poured into steel moulds of 15 mm diameter and allowed to cool to obtain cast rods. The samples were prepared from these cast rods.

Figure.3: (a)Before machining specimens (b)After machining specimens

III.TESTING

The following tests are conducted on the aluminium composites to known their mechanical properties.

3.1 Hardness

Vickers hardness studies were carried out for the investigated materials using Vickers hardness tester (Hardness tester) with 1kg load. The indentation time for the hardness measurement was 15 seconds. An average of four readings was taken for each hardness value.

3.2 Tensile Test

Tensile strength of composites at room temperature was determined using a 100kN universal testing machine. Tensile test was performed using universal testing machine. The test was conducted using strain rate of 2mm/min at room temperatures. The tensile test specimens were prepared using lathe machine according to the dimensions ASTM E8 Standards.

Tensile strength =F/A (N/mm2) ....(1)

Where F = Force (N)

A = cross sectional area of the specimen (mm^2).

3.3 Density:

Density is also a major factor influencing the selection of a material for any application. Density is defined as the mass per unit volume. Mass of the specimen was estimated by measuring the weight of the specimen using an electronic weighing machine having accuracy up to 0.001 mg. The density of the alloy and composites was measured by

Archimedes principle using equation

$$MMC = (\frac{m}{m - m_1}) \times H_2O \quad ....(2)$$

Where MMC - the density of the Al LM25+ Silicon Carbide composite

m - Mass of the composite sample in air

m_1 - mass of the same composite sample in distilled water and

H_2O - density of distilled water-998 kg/m.^{3}

3.4 Poisson's Ratio:

The ratio of lateral strain to linear strain is known as poison's ratio. The poisons ratio of the composite can be calculated by rule of mixtures.

Poisson's ratio (μ) = ($\mu_m \times V_m + \mu_f \times V_f$)........................(3)

Where, μ, μ_m, μ_f – Poisson's ratio of the composite, matrix and dispersed phase respectively;

V_m,V_f – volume fraction of the matrix and dispersed phase respectively.

The poissons ratio of the aluminium is 0.33.

The Poisson's ratio of the silicon carbide 0.15.

3.5 Compression Test

A compression test can be performed on UTM by keeping the test-piece on base block (see in fig.) and moving down the central grip to apply load. It can also be performed on a compression testing machine. A compression testing machine shown in fig. it has two compression plates/heads. The upper head moveable while the lower head is stationary. One of the two heads is equipped with a hemispherical bearing to obtain Uniform distribution of load over the test- piece ends. In cylindrical specimen, it is essential to keep h/d < 2 to avoid lateral instability due to buckling action. Specimen size = h < 2d.

IV.PROBLEM SPECIFICATION

In this project we find which material is best suited for making of wing (AL alloy and AL+SiC). For wing Skelton structure we use NACA 4415 co-ordinates. We apply the boundary conditions on top of the wing.

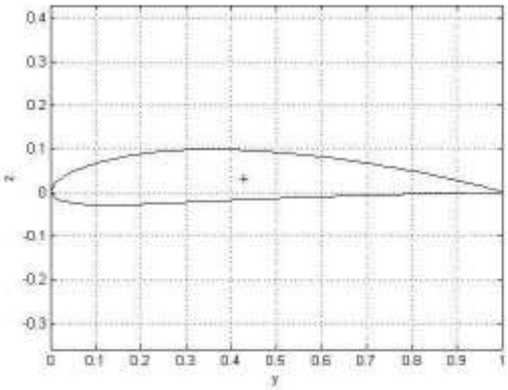


Figure.4: NACA4412 airfoil shape

We fixed one end of the wing and we will apply the pressure 14000N on the top of wing to find out the structural parameters like total deformation, equivalent stress, max principle stress, stress intensity, and also shear stress. Compared to the two materials which material (AL alloy and AL+SiC) has low deformation and stress values that material is best for making of wing.

PROPERTIES	ALUMINIUM	ALUMINIUM + SILICON CARBIDE
Density	2700kg/cm^3	2770 kg/cm^3
Young’s Modulus	68.3GPa	71GPa
Poisson’s ratio	0.34	0.33
Pressure load	14000N	14000N

Table.1: Input Parameters

V.WING DESIGN PROCEDURE

The amount of lift produced by an airfoil depends upon many factors. They are Angle of attack, the lift devices used (like flaps), the density of air, the area of wing, the shape of wing, the speed at which the wing is travelling. Some Factors affecting wing size they are cruise drag, stall speed, take off and landing distance. The first step is to get the airfoil shape in the CATIA V5 R20 part design. As we are considering that wing is designed with only one airfoil throughout, it has to be scaled down accordingly to get the required shape of a wing profile, volume, hanger size.

Figure .5: NACA4412 Airfoil Generation

The Figure 5 shows the NACA 4412 Airfoil generation. For wing Skelton structure we use NACA 4412 co-ordinates. Import the coordinates to CATIA V5 R20 through Microsoft excel then the airfoil shape is generated in CATIA V5 R20. The Figure 4 shows the Airfoil sizing. As the mid wing span is 22.42 m we divide the airfoil in 23 sections. Each Section placed at an equal distance from the reference.

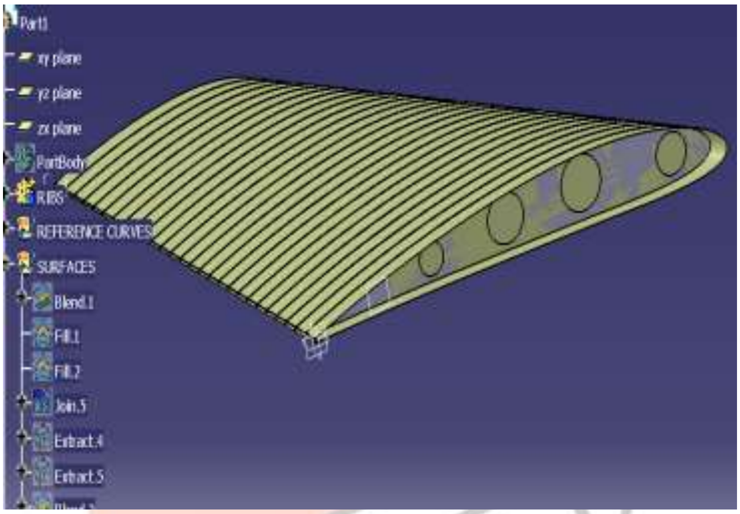


Figure .6: Design of Wing Structure

The above Figure 6 shows the complete design of wing Skelton structure design with spars and ribs. In the wireframe and surface design workbench, the surface for the following sections has been generated accordingly. Each section is padded 50 mm mirror extended so that the airfoil section is converted into the rib section with a thickness of 100 mm. The spars and holes are being created in the wing design as per our assumptions respectively. The complete design of the wing skeleton structure is formed. Before importing the CAT file to the ANSYS workbench, the file has to be converted into IGS or step format.

VI.SOLUTIONS AND DISCUSSIONS

In static structural analysis we are interested to find the total deformation, Von Misses stress which is also known as equivalent stress, shear stress, maximum principal stress, maximum shear stress and stress intensity induced in the Skelton structure of the wing.

Structural Analysis with composite materials

The Figure 7 shows the deformation of aluminium alloy at pressure load 14000N, it shows the max value of deformation is 0.008112.

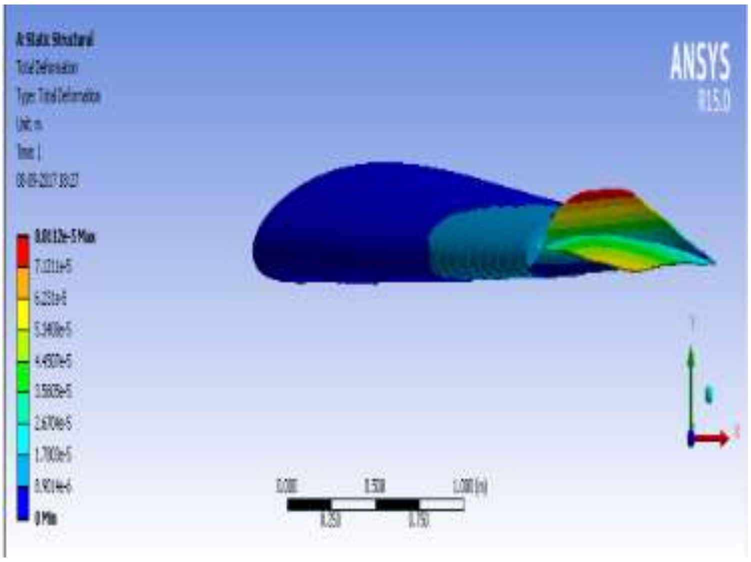


Figure .7: Deformation of Aluminium

The Figure 8 shows the max value of Equivalent stress is 4.9898e6.

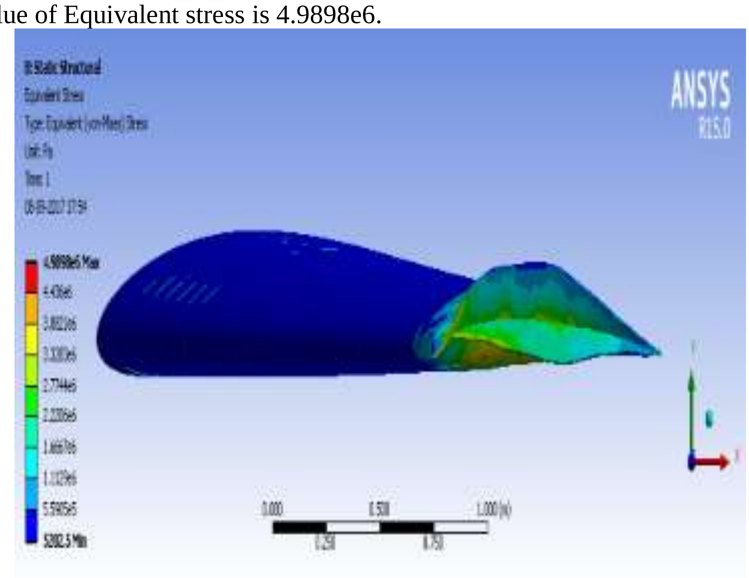


Figure.8: Equivalent Stress of Aluminium

The Figure 9 shows the max value of max principle stress is 5.0698e6.

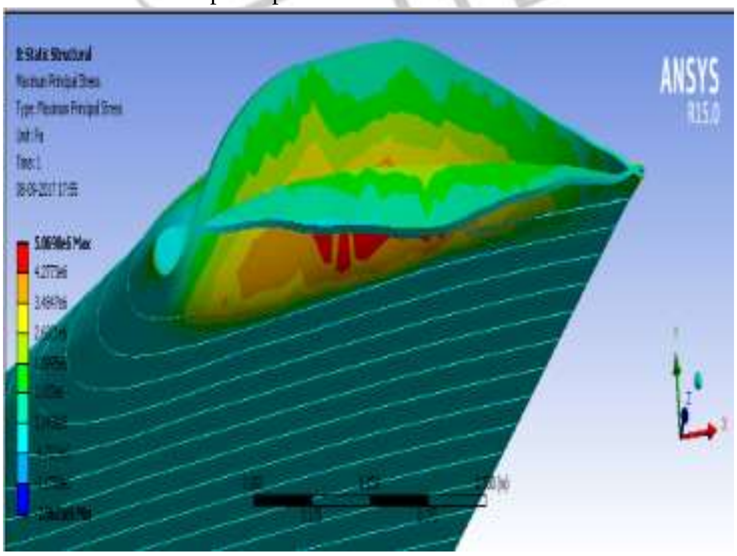


Figure.9: Maximum Principal Stress of Aluminium

The Figure 10 shows the max value of stress intensity is 5.4838e6.

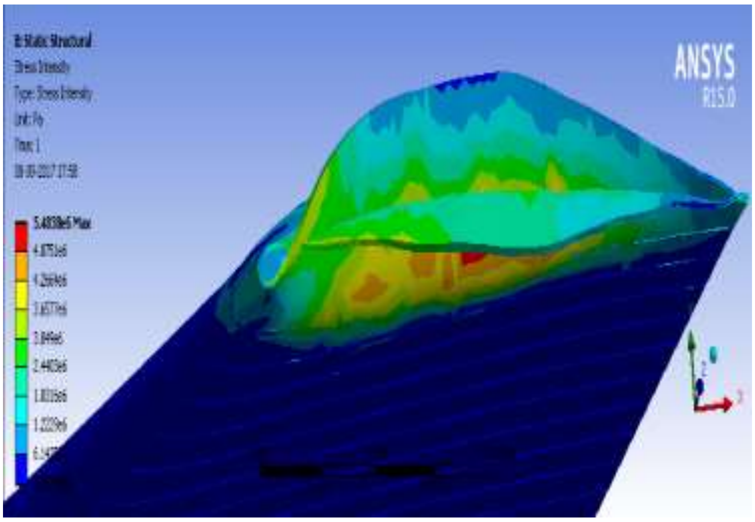


Figure.10: Stress Intensity of Aluminium

The Figure 11 shows the max value of shear stress is 2.012e6.

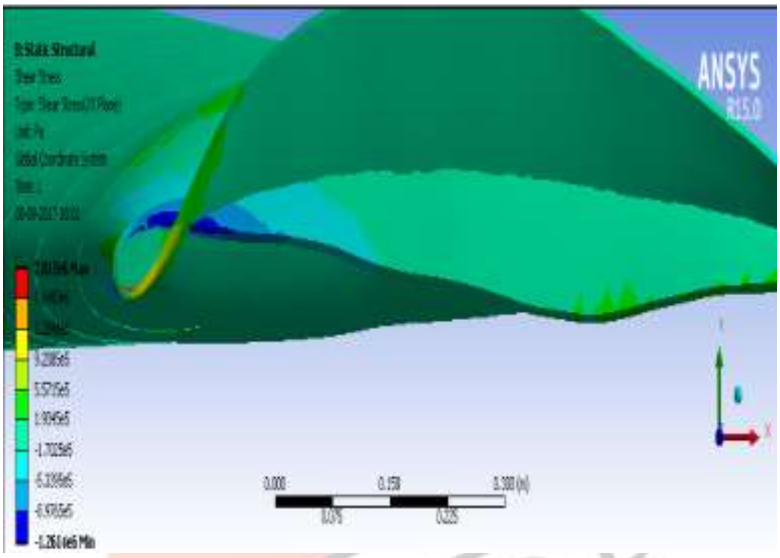


Figure.11: Shear Stress of Aluminium

The figure 12 shows the maximum shear stress is 2.7419e6.

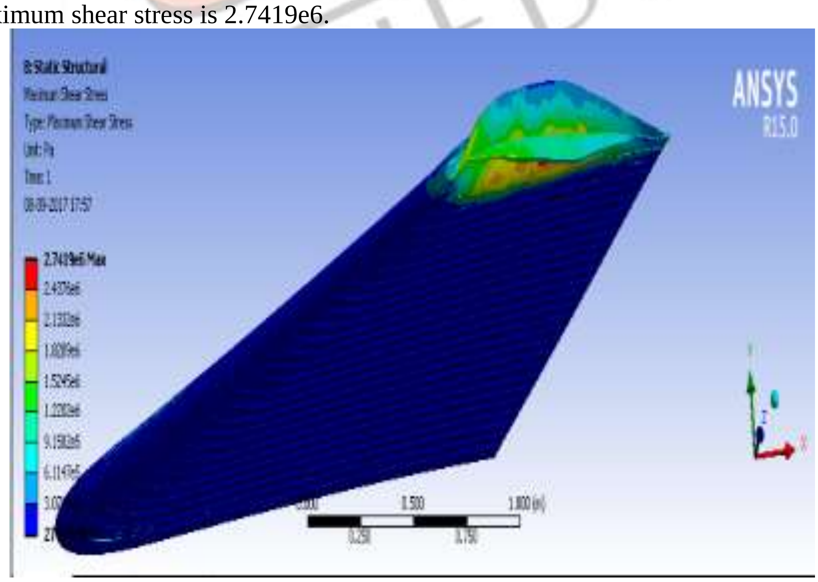


Figure.12: Maximum Shear Stress of Aluminium

Structural Analysis with Al+SiC

In this analysis we fixed one end of the wing and we applied pressure 14000N on the top of the wing with in uniform temperature.

The Figure 13 shows the deformation of AL+SiC is 0.0001002.

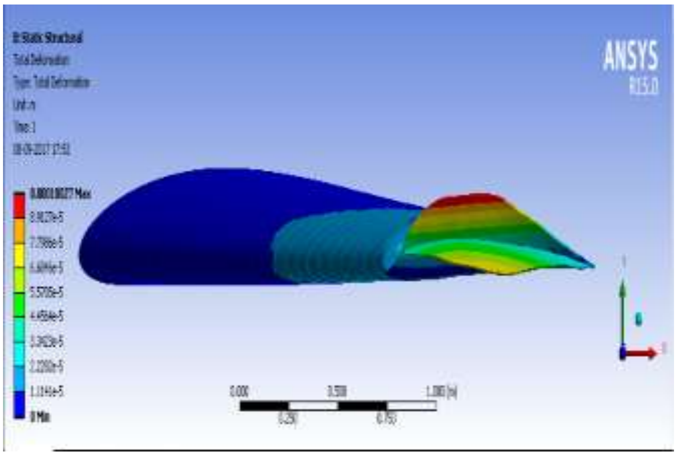


Figure.13: Deformation of Al+Sic

The Figure 14 shows the Equivalent stress of Al+SiC is 4.1695e6.

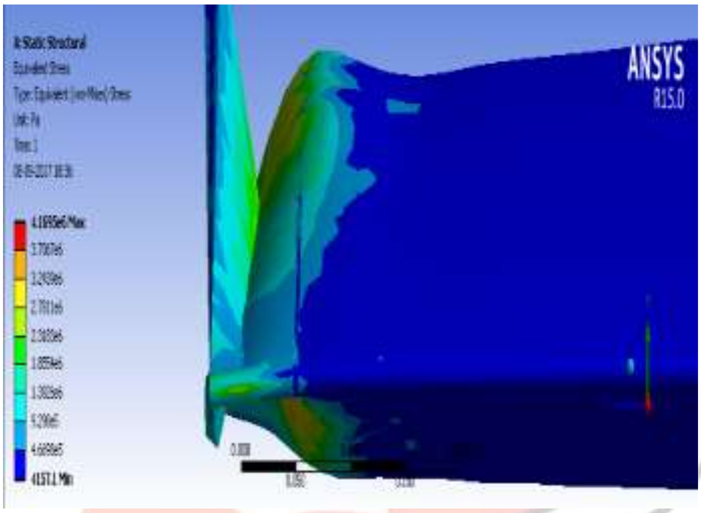


Figure.14: Equivalent Stress of Al+Sic

The Figure 15 shows the maximum principle stress of Al+SiC is 4.1899e6.

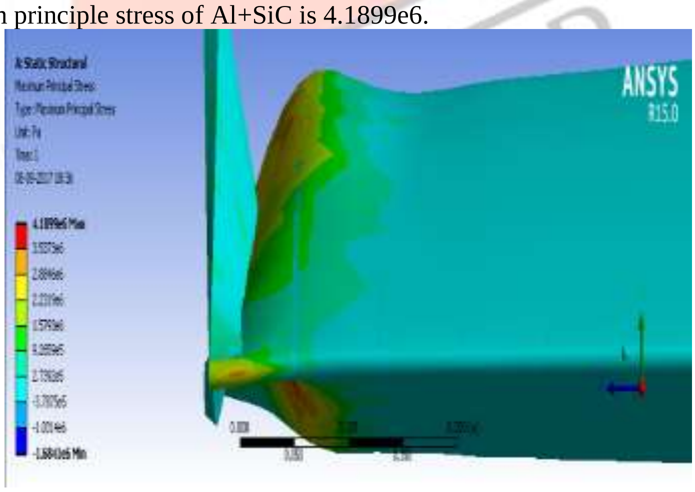


Figure.15: Maximum Principal Stress of Al+Sic

The Figure 16 shows the stress intensity of Al+SiC is 4.5121e6.

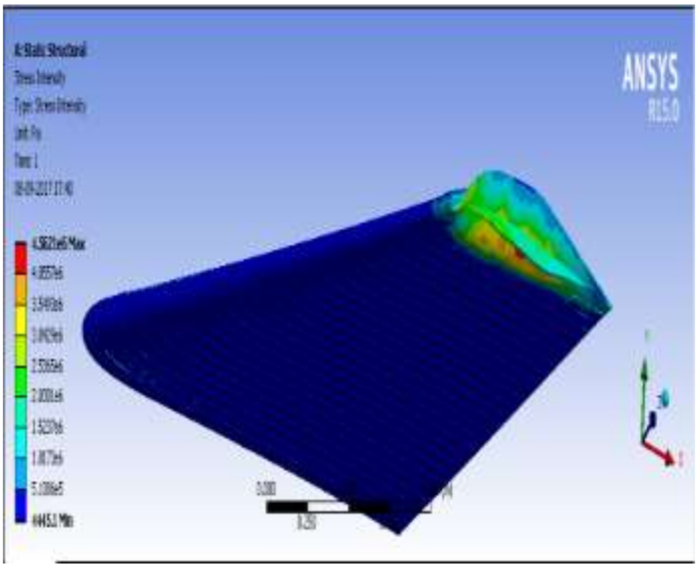


Figure.16: Stress Intensity of Al+Sic

The Figure 17 shows the shear stress of Al+SiC is 1.6588e6.

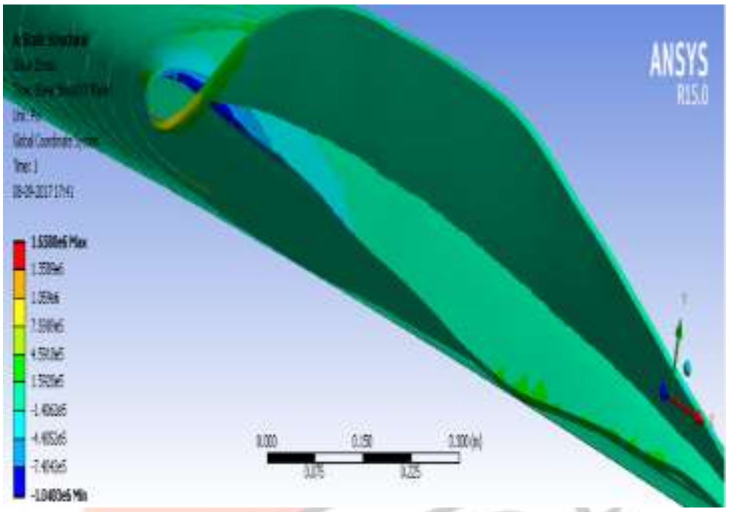


Figure.17: Shear Stress of Al+Sic

The figure 18 shows the maximum shear stress of Al+SiC is 2.2811e6.

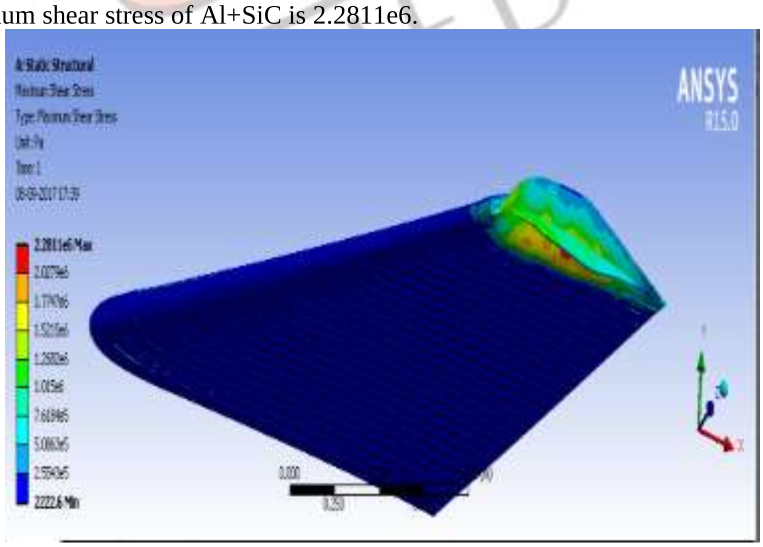


Figure.18: Maximum Shear Stress of Al+Sic

VII.RESULTS

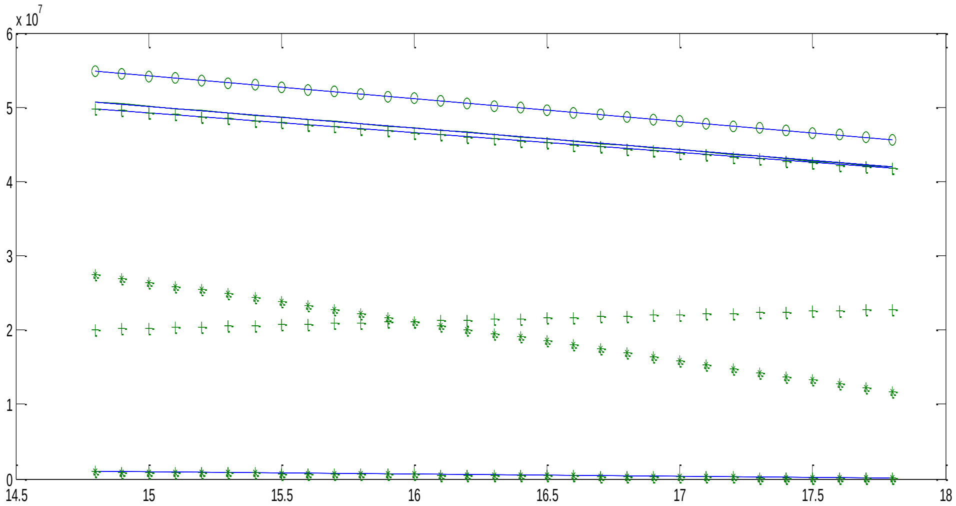
STRESSES	**MAXIMUM**

TOTAL DEFORMATION	0.0001002
EQUIVALENT STRESS	4.1695e6
MAXIMUM PRINCIPAL STRESS	4.1899e6
MAXIMUM SHEAR STRESS	2.2811e6
STRESS INTENSITY	4.5621e6
SHEAR STRESS	1.6588e6

Table.2:Stress Results for Al+Sic

STRESSES	**MAXIMUN**
TOTAL DEFORMATION	0.008112
EQUIVALENT STRESS	4.9898e6
MAXIMUM PRINCIPAL STRESS	5.0698e6
MAXIMUM SHEAR STRESS	2.7419e6
STRESS INTENSITY	5.4838e6
SHEAR STRESS	2.012e6

Table.3: Stresses for Aluminium Alloy



An analysis by varying the parameters was performed in ANSYS software and obtained the results. In order to check the results, a synthesis test was also done in MAT lab. At certain point both values were found to be approximately equal which are the optimum values obtained.

CONCLUSION

From the above results we can conclude that the difference between the values of deformation, equivalent stress, max principle stress, stress intensity and shear stress with Al alloy and Aluminium + Silicon Carbide are minimal. The results obtained are optimum. As the difference between the two result values are minimal. We can use aluminium + Silicon carbide instead of using aluminium alloy in order to give the more strength to the structure. The effect of pressure during take-off condition is more for Aluminium and less for Al + SiC which is strongest and light weight, and also reduces the weight of the wing. Thus we can conclude that at the above assumed loading conditions and constraints flight wing structure will not fail due to material properties. We can conclude that aluminium+ silicon carbide can be replaced with aluminium alloy.

REFERENCES:

[1]. P.B.Pawara,Abhay A Utpat, " Analysis of Composite Material aircraft wing under Static Loading Condition" Elsevier(2014)

[2] Eng.bogdancaloian, Eng.Dorinlozici and eng.Radubisca, 2009"Stress and Modal Analysis Report for Avert Program", DOI 10.13111/ 2066-8201.

[3] Mr. Mayurkymarkevadiya, 2013"CFD Analysis of Pressure Coefficient for NACA 4412".

[4] Md. Shamim Mahmud, 2013 "Analysis of effectiveness an airfoil with BicamberSurface",ISSN 2049-3444, Vol 3, No 5.

[5] Dr.R.Rajappan, V.Pugazhenthi,2013"Finite element analysis of aircraft wing using composite structure",IJES, Vol 2, issue2.

[6] N R PRABHU SWAMY, C S RAMESH and T CHANDRASHEKAR ,2010 "Effect of heat treatment on strength and abrasive wear behavior of Al6061–SiCp composites"

[7]J.D.Anderson Jr. (2007) "Introduction to Flight", fifth edition, The McGraw-Hill companies.

[8] Dr.JanRoskam and Dr.Chuan-Tau, (1997), „Airplane Aerodynamics and Performance".

[9]. Xi P, Zhang BY, Ning T. Intelligent product design based on open knowledge representation. Acta Aeronautic et Astronautic Sinica 2012;33(9):1746–54 Chinese.

[10]. Anemaat WA, Schueler KL. Airplane layout design using object oriented methods. 1997. Report No.: AIAA-1997-5510.

[11]. Feng HC, Luo MQ, Liu H, Wu Z. A knowledge-based and extensible aircraft conceptual design environment. Chin J Aeronaut 2011;24(6):709–19.

[12]. La Rocca G, van Tooren MJL.Knowledge-based engineering approach to support aircraft multidisciplinary design and optimization Aircraft 2009;46(6).

[13].NACA 4412 airfoil coordinates.

[14].Aeronautical text book by Raymer.