

Heat Transfer Analysis of Carbon-Carbon Composite Materials in Gas Turbine Combustion Chamber

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Abstract

The gas turbine combustion chamber requires special characteristics such as thermal resistance, corrosion resistance, wear resistance. At present the steel, metal alloy and super alloys are used in gas turbine combustion chamber. It is subjected to high thermal stress on gas turbine combustion chamber region. It reduce overall efficiency of the power plant. In this paper, the steel with carbon-carbon composite gas turbine combustion chamber are designed and thermal analyses are carried out by using ANSYS. The analytical result of the proposed design is compared with existing combustion chamber.

Keywords: Carbon-Carbon Composite, Combustion Chamber, ANSYS13.

1.Introduction

Carbon-Carbon(C-C) Composite materials with a spectrum of properties and applications in various areas. These composites are made of fibres in various directions and carbonaceous polymers and hydrocarbons as matrix precursors [1]. The carbon fibres have proved to be the main reinforcement for advanced composites for a wide range of applications. The majority of products still belong to high technology space and aeronautics [2]. Composite materials potentially offer an efficient solution for these design problems due to their high strength to weight characteristics and their high heat resistant properties [3].

The Fig.1 shows the combustion chamber is the most critical part of the gas turbine power plant. The chamber has to be design so that the flame is self-sustaining and the temperature of the products of combustion is sufficiently below the maximum working temperature of the turbine. To achieve these goals, the combustion chamber can be divided into two areas the primary zone and the secondary zone. The primary zone is where the majority of the fuel combustion takes place.

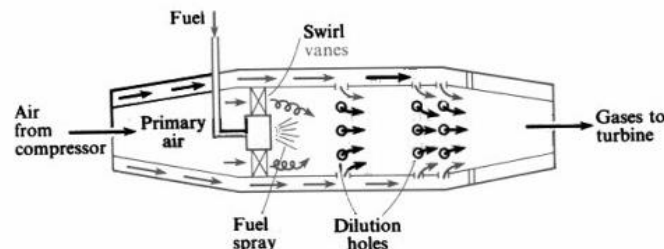


Fig.1. Combustion chamber

The fuel must be mixed with the correct amount of air so that a stoichiometric mixture is present. In the secondary zone, unburned air is mixed with the combustion products to cool the mixture before it enters the turbine.

ANSYS Mechanical technology incorporates both structural and materials non linearities. ANSYS Multiphysics software includes solver for thermal, structural, CFD, electromagnetic, and acoustics and can couples these separate physics together in order to address multidisciplinary applications. ANSYS software is also used in Civil Engineering (ANSYS/CivilFEM), Electrical Engineering, physics and chemistry design.

In this work combustion chamber is designed by pro-E and thermal analyses are carried out by using ANSYS. The ANSYS result of existing model is compared with proposed model.

2. Related Works

J.W. Klett et.al, presents the thermal conductivity of specific types of composites were determined and the fiber/matrix interface plays a dominant role that particular type of fiber volume fraction in the transverse thermal conductivity [4]. M.A. Sheikh et.al., proposed the thermal transport character of a CMC can be modelled using a representative unit cell developed from the micrographs, obtained through SEM analysis [5]. It is expected that this will lead to the establishment of a generic material modelling strategy for thermal transport analysis of more complex woven composite materials.

Lum R et.al., present in this paper coated carbon-carbon composite of the kind incorporation carbon fibers in a carbon matrix also incorporates in at least a region thereof other fibers of a different axial coefficient of thermal expansion from that of the carbon fibers the other fibers being arranged in relation to adjacent carbon fibers so as to provides in combination with the carbon matrix a coefficient of thermal expansion of that region of the composite which is compatible with that of an anti oxidation coating on the surface of the region[6].

F .Zander and R.G.Morgan introduce the Octane fuel never reaches temperatures in excess of the material limits. As this may represent an engineering design that could be flown in the near future on long duration scramjet flight tests. This work will be extended to include different fuel types and combustor configurations enabling analysis of scramjets currently being considered for flight. This paper justifies the continued analysis and further work [7].

The paper presents the different aspects considered in the thermal analysis, based on the design and analysis results a breadboard model. The correlation between The ANSYS result of existing model is compared with proposed model results is shortly discussed.

3 Proposed Research Work

3.1 Design of Combustion Chamber

The Fig.2 shows the combustion chamber is constructed using a concentric tube design. It is modelled after the design of several different gas-turbines .The inner shell, the flame tube, is made of 22-gauge perforated steel. Air flow from the compressor is fed through the flame tube as well as around its sides. The air in the flame tube is burned with the propane, while the air on the outside of the flame tube is used to cool the products of combustion before they enter the turbine. The Table 1 shows the properties of steel and Table 2 shows the properties of C-C composite.

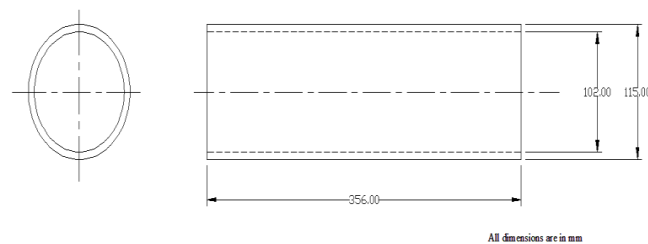


Fig.2.Chamber shell

Table 1. Properties of steel:

Sl.no	Material	Density (Kg/m ³)	Specific heat (J/Kg K)	Thermal conductivity(W/m K)
1	Carbon silicon steel	7817	446	51.9
2	Stainless steel	8055	480	15.1

Table 2.Properties of C-C composite:

Sl.no	Material	Density (Kg/m ³)	Specific heat (J/Kg K)	Thermal conductivity(W/m K)
1	Carbon fiber transverse	1928	921×10^{-6}	4
2	Carbon matrix	1800	712×10^{-6}	10

3.2 Thermal calculation for stainless steel with coated C-C:

The thermal calculation for stainless steel with coated Carbon-Carbon composite as shown in Fig.4 the calculations are given below.

$$l_1 = 3.5 \times 10^{-3} \text{ m}, l_2 = 3.25 \times 10^{-3} \text{ m}, k_1 = 11.5 \text{ W/m.K}, k_2 = 15.5 \text{ W/m.K}, T_1 = 1000^\circ\text{C} = 1273 \text{ K}, T_\infty = 30^\circ\text{C} = 303 \text{ K}, h = 50 \text{ W/m.K}$$

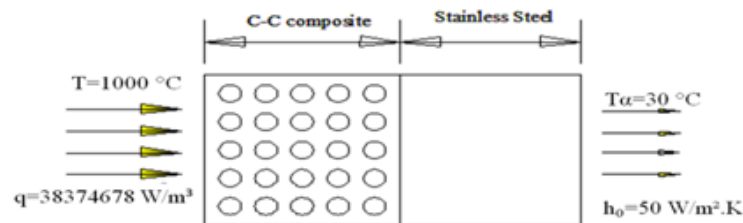


Fig.4. stainless steel with coated C-C:

(i) Heat transfer per unit area (heat flux),

$$Q = (T_1 - T_\infty) / ((1/h_i.A) + (l_1/k_1.A) + (l_2/k_2.A) + (1/h_0.A))$$

$$= (1273 - 303) / ((3.5 \times 10^{-3} / 11.5) + (3.25 \times 10^{-3} / 15.1) + (1/50))$$

$$Q = 47271.92 \text{ W/m}^2.$$

(ii) Temperature at the midpoint,

$$Q = (T_1 - T_2) / R_1$$

$$Q = (T_1 - T_2) / (l_1 / k_1.A)$$

$$47271.92 = (1273 - T_2) / (3.5 \times 10^{-3} / 11.5)$$

$$T_2 = 1258.61 \text{ K}$$

$$T_2 = 985.61^\circ\text{C}$$

(iii) Temperature at the outer surface,

$$Q = (T_2 - T_3) / R$$

$$T_3 = T_2 - Q(l_2 / k_2.A)$$

$$= 1258.61 - 47271.92(3.25 \times 10^{-3} / 15.1)$$

$$T_3 = 1248.43 \text{ K}$$

$$= 975.43^\circ\text{C}$$

(iv) Thermal gradient for Element 1

$$-dT/dx = -(1000 - 985.61) / 3.5 \times 10^{-3}$$

$$= -4111.42^\circ\text{C/m}$$

Thermal gradient for Element 2

$$= -(985.61 - 975.43) / 3.25 \times 10^{-3}$$

$$= -3132^\circ\text{C/m}$$

4. Design of Coated C-C with Steel in ANSYS

ANSYS Mechanical and ANSYS Multiphysics software are self contained analysis tools incorporating pre-processing (geometry creation, meshing) solver and post processing modules in a unified graphical user interface. These are general purpose finite element modelling packages for numerically solving a wide variety of mechanical problems including static/dynamic structural analysis (both linear and non linear) heat transfer and fluid problems, as well as acoustic and electromagnetic problems. There are four types pre-processor, Meshing, solution and post processor are given below [8].

1. Pre-processor>Preferences >Thermal>ok, i) Element type>add>solid>quad 4node55>ok, ii) Material properties>temperature units>Celsius>ok, iii) Material models1>Thermal>conductivity>isotropic>KXX = 4 W/m K, C = 921e-6 J/Kg K, ρ = 1928

Kg/m³, iv) Material models> Thermal> conductivity> isotropic>KXX = 10 W/m K, C = 712e-6 J/Kg K, ρ = 1800 Kg/m³, v) Material models 3>Thermal>conductivity>isotropic>KXX = 15.1 W/m K>C = 480 J/Kg K> ρ = 8055 Kg/m³, vi) Modelling>create>area>rectangle>by two corners>Width = 6.75e-3m> Height = 6.75e-3m, vii) Modelling>create>area>circle>solid circle>radius = 0.25e-3m, viii) Modelling>operate>Booleans>subtract>ok, ix) Modelling>operate>Booleans>glue>ok. Fig 3 shows the modelling of coated c-c with steel.

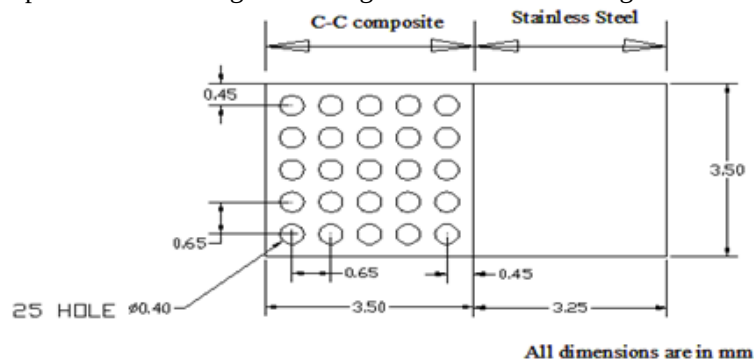


Fig .3. Model of coated C-C with steel

2. Meshing>mesh attributes>picked areas>material model1>selected area>ok. xi) Meshing>mesh attributes>picked areas>material model2>selected area>ok. xii) Meshing>mesh attributes>picked areas>material model3>selected area>ok. xiii) Meshing>mesh tool>mesh>ok. . Fig 4 shows the meshing of coated c-c with steel.

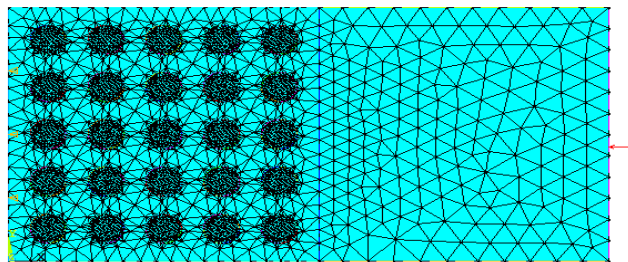


Fig. 4. Mesh model of coated C-C with steel.

3. Solution> define load>apply>Thermal. i) Temperature >on lines>pick line>Temperature = 1000°C. ii) Convection>on lines>pick lines>ok>Film coefficient = 50 W/m² K> Bulk temperature = 30°C. iii) Heat generation>on lines>pick lines>ok>Heat generation = 3, 83, 74,678 W/m³. Solve>current LS>ok.

4. General post processor>plot results>contour plot> i) Nodal solution>DOF > temperature distribution>ok. ii) Nodal solution>thermal gradient>ok.iii) Nodal solution>thermal flux>ok

5. Result and Discussions

The temperature distribution of coated c-c with steel can be observed as shown in Fig.5. The most temperature observed in C-C composite material minimum amount of heat dissipated in outer surface steel. Fig.6 shows the comparison of temperature distribution with node in different material [9]. The temperature distribution is found to be very low in coated c-c with steel and very high in the steel material.

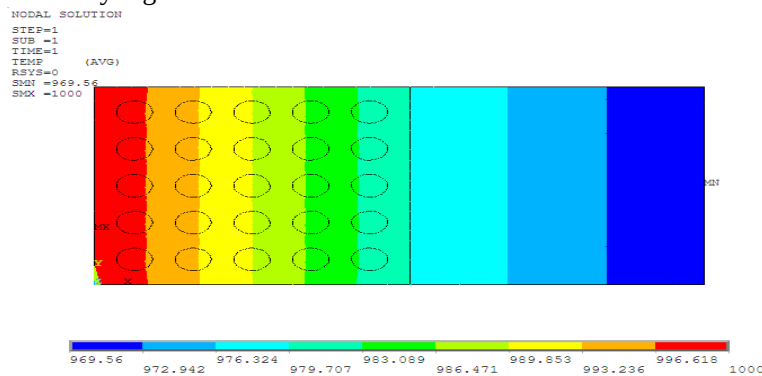


Fig.5. Temperature distribution

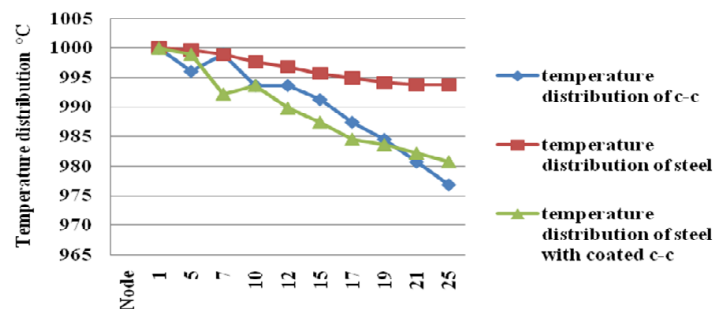


Fig.6. Node Vs Temperature distribution

The Thermal gradient of coated c-c with steel can be observed as shown in Fig.7. The Thermal gradient observed in C-C composite material minimum also. Fig.8 shows the comparison of Thermal gradient with node in different material. The Thermal gradient is found to be very low in coated c-c with steel and C-C composite material when compare to steel material [10]. Also the different heat conditions are applicable in the coated C-C with steel.

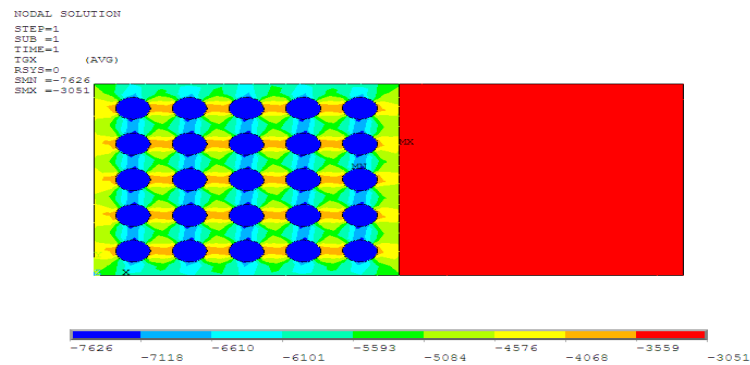


Fig.7. Thermal gradient

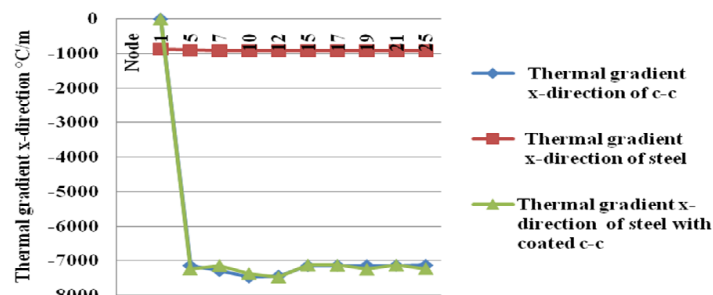


Fig.8. Node Vs Thermal gradient

The Thermal flux of coated c-c with steel can be observed as shown in Fig.9. The Thermal flux observed in C-C composite material. Fig.10 shows the comparison of Thermal flux with node in different material. The Thermal flux is found to be very low in coated c-c with steel and C-C composite material when compare to steel material. Because it is heat restricted in carbon fibre is more also in coated c-c with steel material. The heat flux of C-C composite combustion chamber is 3% less than the steel. It reduce the temperature of wall at the outer surface of the combustion chamber without insulation condition

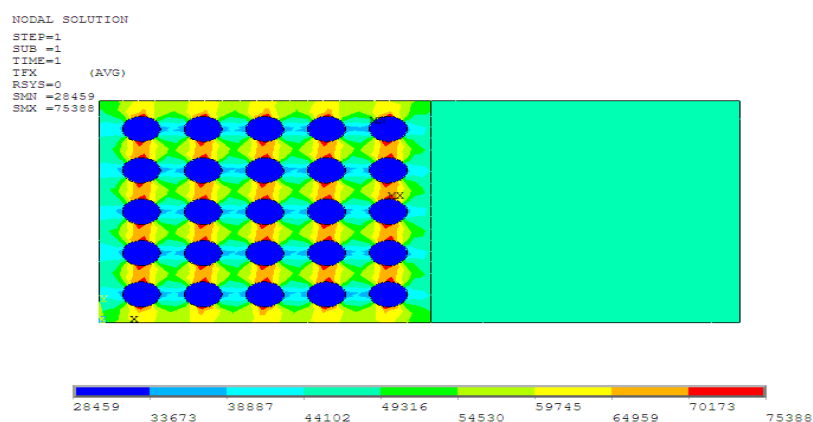


Fig.9. Thermal flux

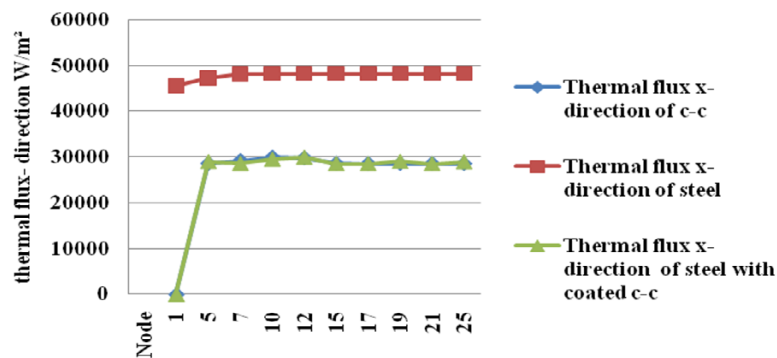


Fig.10. Node Vs thermal flux graph

6. CONCLUSION

In this paper the structure of combustion chamber is designed by pro-E and thermal analyses are carried out by using ANSYS. The ANSYS result of existing model is compared with proposed model. The heat flux of carbon-carbon composite combustion chamber is 3% less than the steel, and it reduce the temperature of wall at the outer surface of the combustion chamber without insulation condition. So it is increased effectiveness of combustion chamber and also it will increase efficiency of the plant.

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