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Investigation on Structural Stability of CMSX-4 and RENE 77 made Gas Turbine Guide Vanes with Impingement Cooling

Dr. R. Saravanan[1], M. Karuppasamy[2]

[1]*Principal & Professor, Mechanical Engineering, Elenki Institute of Engineering and Technology, Affiliated to JNTU Hyderabad, Patelguda, Hyderabad -502319, TS, India.*

[2]*Associate Professor, Department of Mechanical Engineering, S.Veerasamy Chettiar College of Engineering and Technology, Puliangudi -627855, Tamil Nadu, India.*

***Abstract*— According to the thermodynamics increase of heat input increases the work output as we as efficiency. The gas turbine is a such a thermal device and its inlet temperature is proportional to the thermal efficiency and power output. Higher temperature effects on structural stability of turbine components which expose at elevated temperature. This brings the need for investigation of stability of them before they actually fabricate. This research investigates the structural stability of fixed blade of gas turbine at elevated temperature. The CMSX-4 and RENE 77 are considered for blade materials. The impingement type cooling design is considered for both types of blades. The cooling design is hollow portion and they greatly influence on the structural stability of gas turbine components. This research focuses on the material influence on fixed blade with impingement cooling design. The Pro –E and ANSYS R14 were used for design and FEM analysis respectively.**

***Keywords*— Structural stability, ANSYS, Pro-E, Gas turbine, Guide Vane, Impingement.**

I. INTRODUCTION

Applications of gas turbines are wide in range like aircraft, marine propulsion, locomotive, power generation, and other industrial prime movers. For increasing thermal efficiency and work output in gas turbines, the higher input temperatures encountered ranging from 1000 to 1500°C [1-3]. In particularly aerospace applications operates gas turbines higher inlet temperature like 1,727°C [4-6], and with a high pressure ratio about 50 at compressor [6]. Such high temperatures causes thermal damages (melting, corrosion, oxidation and erosion) [7] and degradation of local or global structural strengths of blades, vanes and other components and it was estimated that half of the lifespan of the blades gets reduced due to small temperature difference by improper cooling [3,6,9]. The damages include blade trailing-edge cracks [8], buckling and risk of blade failure [11], thermal-fatigue [8,10,11].

Many studies were conducted on optimization of lip thickness to slot height ratio (t/H) in trailing edge cooling of blades and vanes [12 -17] in which Kacker et al. [12,13] considered lip thickness constant to estimate film cooling effectiveness, Taslim et al [14,15] varies slot geometries and blowing ratios. The t/H ratio from 0.5 to 1, decrease the overall film-cooling effectiveness by about 10% [14-16]. The decreases of t/H ratio, increases the film-cooling effectiveness [17-19]. [20] considered a a rectangular divergent channel which consists of serpentine shape with ribs, dimples/protrusions, guide vanes, and pin fins at the tip turning the region for his heat transfer studies. [21] studied the cooling performance at tip surfaces of guide vanes and blades at turning regions and insisted the importance of proper design to obtaining desired effects. [22] recommended installing guide vanes in the tip turning regions most suitable way to improve cooling of tip surfaces. [23] insisted that selection appropriate cooling technique with respect to configuration is must. The authors suggested two pass channels cooling at moving blades. This research work investigates with materials behaviors at elevated temperature for impingement cooling design on gas turbine fixed blade (guide vane). The Pro-E and ANSYS are employed to design and analysis. ANSYS is generally the preferred tool for analyzing structural stability. [24] used CATIA and ANSYS to design and investigate the structural stability of various components of Two-Wheeled Inverted Pendulum. In later [25] investigated the suitability of Kevlar29/epoxy composite for drive shaft. The influence of cooling design such as impingement and shower head type on gas turbine guide vanes which are made up of Nimonic 901[26], RENE 77 [27], CMSX 4 [28]. The sample guide vane of gas turbine is shown in Figure I. This research work investigates the material suitability for the gas turbine guide vanes with impingement cooling design. The design softwares like PRO/E and ANSYS 14.5 used for modelling and analysis of material stability under high temperature.

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II. Materials And Methods

The materials which considered for analysis are CMSX 4 and RENE 77. The cooling type in guide vane is impingement type. The Structural Stability investigations are by means of Displacement analysis, Stress analysis and strain analysis. The Design softwares involved are Pro-E for guide vane design, modelling and ANSYS 14.5 for performing Finite Element Analysis.

CMSX 4

It is a single crystal super alloy and gives more stability at elevated temperature. Its significant properties at high temperatures includes impact strength, rupture strength, fracture toughness. The blades which made up of CMSX-4, exhibited good performances as well as extended life span [29-32]. Hence its physical and mechanical properties were included in this analysis of structural stability of specified cooling designed guide vanes of gas turbine and reduced weight [30].

RENE 77

It is preferred for high temperature applications about 1000^{o}C like aviation, petroleum, gas turbine, space flight, ship, etc. because of its significant properties at elevated temperatures like excellent oxidation resistance, with stand at long term stress, creep properties, reliable in physical and chemical properties, good impact and toughness strengths etc. values of such unique properties were included in the analysis.

Structural Analysis

The gas turbine guide vane is modelled in Pro-E. Then it is used for messing and conducting structural analysis in ANSYS 14.5 work bench. The dimensional particulars of the guide vane with impingement cooling are furnished in Figure II. The 3D meshed model is presented in Figure III. The structural analysis like stress analysis, strain analysis and displacement analysis were considered. The comparative study of materials involved in manufacture them is focused on this research. The young's modulus 294000 MPa, material density 0.00000774 kg/mm3, Poisson Ratio 0.3 were considered for CMSX 4 made blades. In case of RENE 77 made blades, the young's modulus 200000 MPa, Poisson Ratio 0.30, material density 0.000077 kg/mm3. In the meshed model made with 186 nodes, and pressure 0.188 N.mm2. The displacement analysis carried at ANSYS 14.5 work bench.

The displacement with respect to turbine load was observed and shown them for CMSX 4 made blades in Figure IV and for RENE 77 made blades in Figure V. The maximum displacements were observed on the concave side of cooling passage nearby its sharp turning. The stress analysis for the above said blades (Figure VI for CMSX 4 made blades and Figure VII for RENE 77 made blades. The strain analysis details are shown in Figure VIII for CMSX 4 made blades and Figure 9 for RENE 77 made blades.

Figure I Fixed blade (Guide vane)

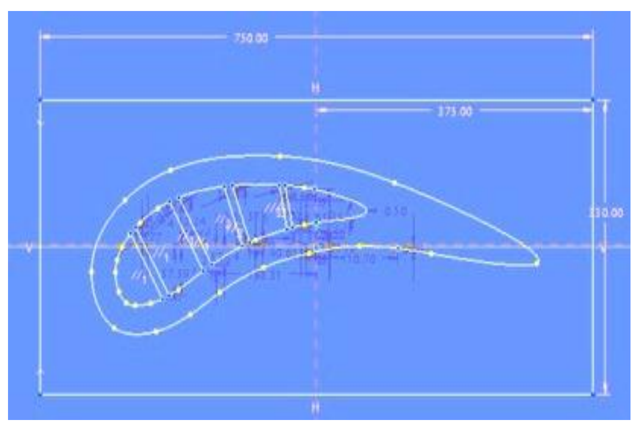

Figure II 2D-model of Guide vane with impingement cooling design

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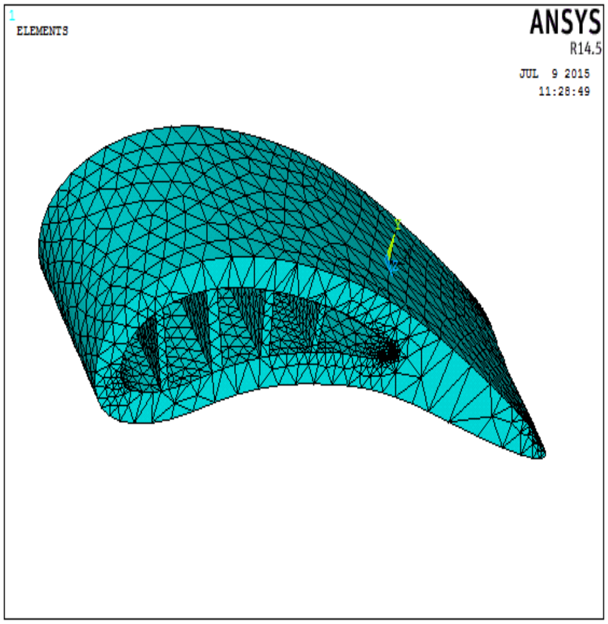

Figure III Meshed model of Guide vane with impingement cooling design

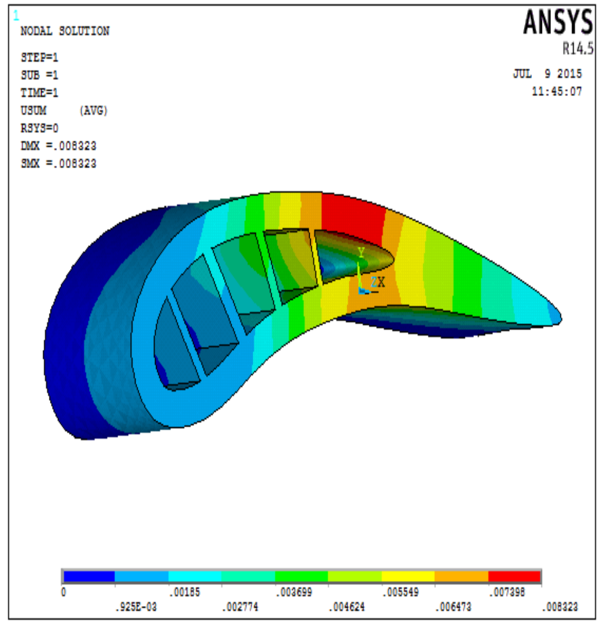

Figure V The displacement analysis for RENE 77 made blades

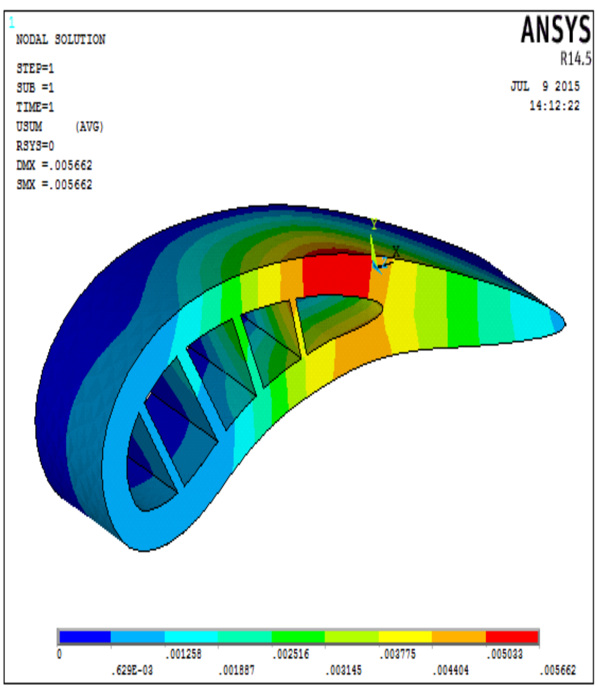

Figure IV The displacement analysis for CMSX 4 made blades

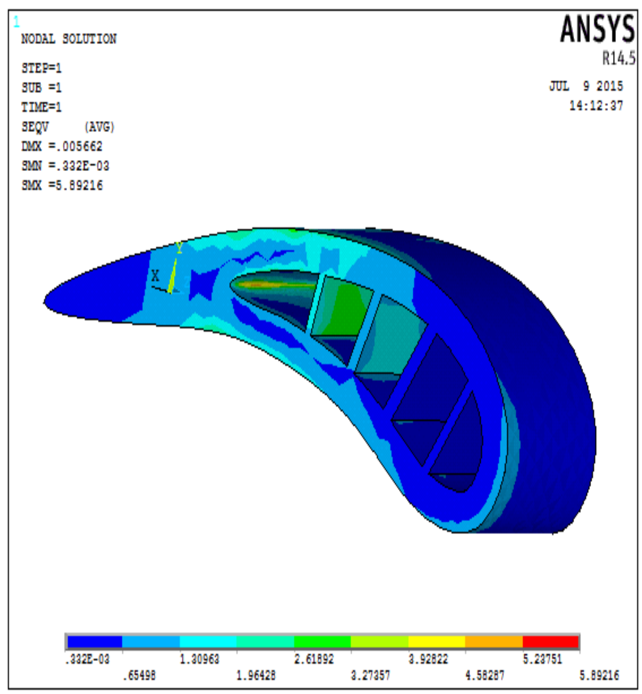

Figure VI The stress analysis for CMSX 4 made blades

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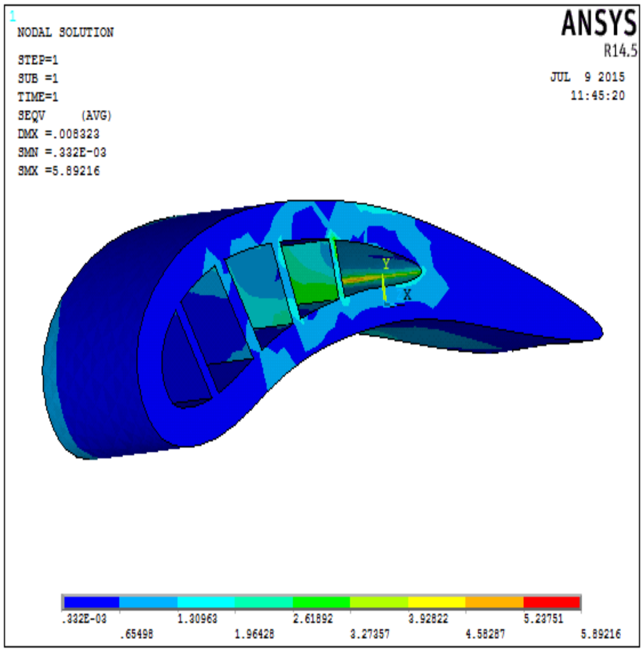

Figure VII The stress analysis for RENE 77 made blades

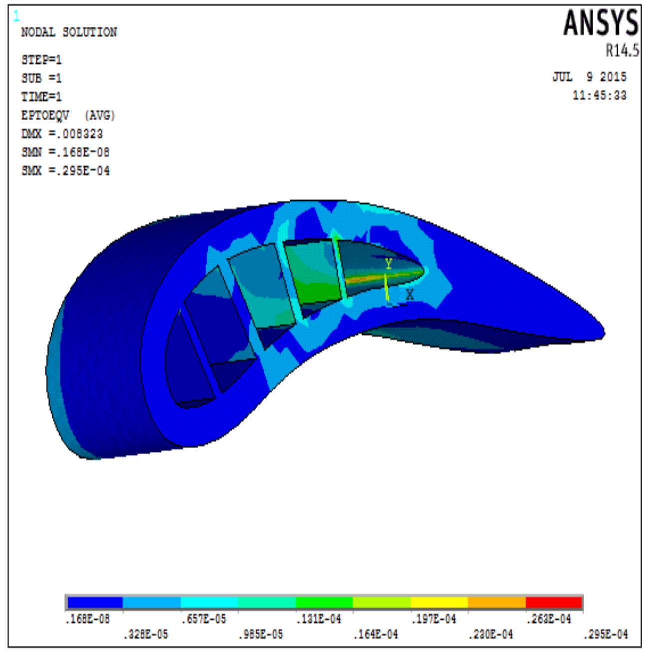

Figure IX The strain analysis for RENE 77 made blades

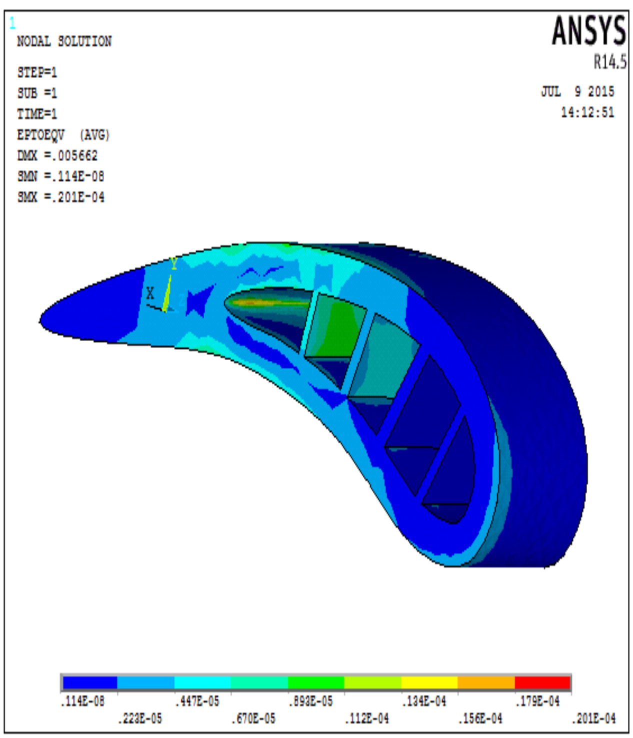

Figure VIII The strain analysis for CMSX 4 made blades

TABLE I
RESULTS OF STRUCTURAL ANALYSIS

Guide Vane Made Up of	Displacement (mm)	Stress (N/mm^2)	Strain
CMSX-4	0.005662	5.89216	0.201e-4
RENE-77	0.008323	5.89216	0.295e-4

III. RESULTS AND DISCUSSIONS

The structural analysis on CMSX 4 and RENE 77 made guide vanes with impingement type cooling design were carried out and reported results in the Table1. The results are compared with respect to materials for displacement in Figure X, for stress in Figure XII and for strain is in Figure12. From the results, it is revealed that both the materials are performing well under in the tested condition. The stress bearing capacity per square millimeter little higher for CMSX 4 (Refer Figure X to Figure XII). The RENE 77 little more flexible. The higher values of stress, strain and displacements were noticed at and nearby sharp turning of cooling design.

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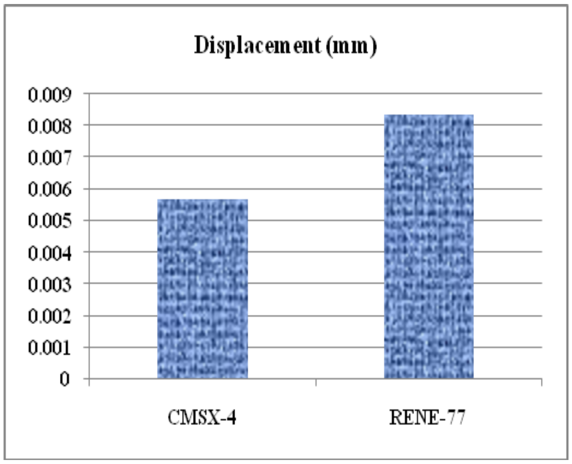

Figure X. The Results of Displacement Analysis

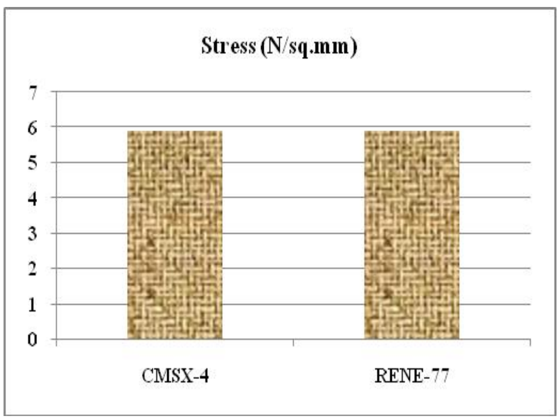

Figure XI. The Results of Stress Analysis

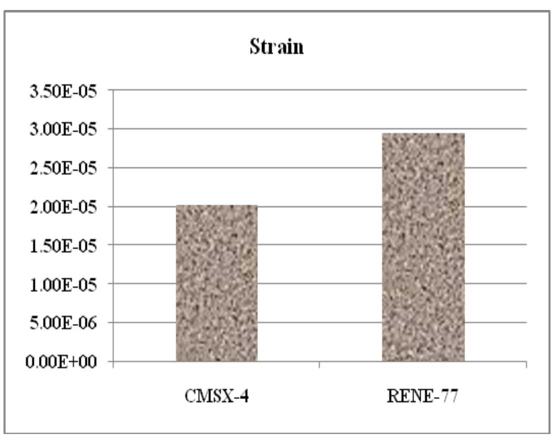

Figure XII. The Results of Strain Analysis

IV. RESULTS AND DISCUSSIONS

The structural analysis on CMSX 4 and RENE 77 made guide vanes with impingement type cooling design were carried out and reported results in the Table1. The results are compared in terms of displacement in Figure X, stress in Figure XI and for strain is in Figure XII. From the results, it is revealed that both the materials are performing well under in the tested condition. The stress bearing capacity is a little higher for CMSX 4 made blades than RENE77 made blades (Refer Figure X to Figure XII). The RENE 77 little more flexible. The higher values of stress, strain and displacements were noticed at and nearby sharp turning of cooling design.

V. CONCLUSION

The fixed blade of Gas turbine with impingement cooling design considered with two different materials (CMSX 4 and RENE 77). The both materials are capable of withstanding loads at elevated temperature. In which the RENE 77 is little more flexible than CMSX 4. The higher values of stress, strain and displacements were observed at the narrow turning of cooling design. The narrow turning in the cooling design may be designed as wide as much as possible to avoid stress concentration.

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