Report on Thermodynamic and emission performance analysis of CMC bladed gas turbine Held on /Accepted– 02.03.2021

Date of Event	**02.03.2021**
Student/Faculty Activity	Thermodynamic and emission performance analysis of CMC bladed gas turbine
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ABSTRACT

Increasing in the turbine rotor inlet temperature improves the aviation gas turbine efficiency, while on the other hand, but also leads to a higher requirement for blade cooling air, which in turn reduces the gain in efficiency achieved by increasing temperature. Turbine rotor inlet temperature has been increasing with the entry of highly-efficient gas turbines have been developed for the last decades for the aviation market. Around one fifth of the compressed air is extracted from the compressor and is used for blade cooling purposes and is thus not used in the actual power/thrust generation process, which has a negative impact on the engine efficiency. For this reason, new cooling methods and hot-gas path component materials that will be compatible with these high temperature's gases are among the areas being analysed. The ceramic-matix-composite (CMC) material have the potential to reduce or eliminate the need of cooling of hot-gas - path component i.e blades of turbine thereby increasing aviation engine efficiency. In the present work firstly, the power output, thermal and exergy efficiencies and emission performance were calculated for ceramic-matrix-composite bladed, gas turbine. The amalgamation of properties of both ceramic fibers and ceramic matrix gives CMC materials the advantage of high fracture strength with high elastic moduli. By reducing the coolant flow rate for the turbine blade, the gas turbine efficiency is increased. Result shows that by increasing the TRIT, turbine engine efficiency and specific work output are both increased. It has also been observed that emission performance of the gas turbine also gets enhanced.

Introduction

CMCs are a subgroup of composites where ceramic reinforcements are embedded in ceramic matrix. They possess the fundamental properties of ceramics along with additional properties imparted by the reinforcements, thus, overcoming the limitations of pure ceramics [[1-3]]. To make this happen, there must be suitable reinforcements for the matrix as well as a suitable fabrication methodology [[4]]. CMCs are broadly classified as oxides and non-oxide based. Oxide CMCs have oxide fibers embedded in oxide matrices where components can be different ceramic compositions like Al_2O_3, MgO, ZrO_2 etc. or their mix¬tures like Al_2O_3–SiO_2, Al_2O_3–ZrO_2, $Al_2O_3 - SiO_2 - ZrO_2$, mullite-SiOC etc. Among the available oxide fibers, alumina fibers are the most common oxide CMC fibers which are commercially available in the market. Their oxidation resistance characteristic makes them a better candidate for structural applications upto 1200°C without any additional coating [[24]] [[25]] [[26]] [[27]] [[28]]. Non-oxide CMCs include C/C, C/SiC, SiC/SiC and other carbides and nitrides fiber and matrix combinations. Unlike oxide CMCs, non-oxide CMCs can operate at higher operating temperatures but are susceptible to oxidation and presence of water vapour at such temperatures pose a deteriorating effect. Among these non-oxide CMCs, a great number of papers have particularly been published on SiC/SiC CMCs which has been identified as a good candidate for critical components of gas turbine engines.

High temperature bearing capability coupled with high fracture toughness when compared ceramics and low weight when compared to metal/metal-alloys have attracted a lot of research in development and application of these materials in aerospace sectors like rocket engines, launch vehicles, spacecrafts, passenger and military airplanes. In gas turbines, CMC can replace conventional nickel-based alloys both in stationary components like combustion chambers, guide vanes, shrouds, exhaust systems and moving components like gas turbine blades.

Mark and Arun [[29]] in their research on examining oxide CMCs for gas turbine combustor predicted that using YAG in substitution for alumina Al_2O_3 could increase the gas turbine inlet temperature to ~1400 C. It was also stated that coating N720/Alumina composite with alumina Friable Graded Insulation (FGI) coating could allow the turbine inlet temperature of ~1350 C which is ~150 C above the uncoated condition. Field testing on Centaur* 50S engine combustor liner made up of AI_2O_3/AI_2O_3 CMC with FGl coating has shown that the material could survive more than 25000 hours of high temperature environment [[30]]. This period was found to much greater than the maximum life of about 15000 hours for non-oxide CMC liners with EBC. The AMAIGT program report [[31]] published after a decade of research on HiPerComp® CMC material for the (7FA-class gas turbine engine) first stage shrouds and combustor liner has showed that the shroud performed satisfactorily for more than 7,000 hours of field engine testing and the combustor liner material was able to sustain 12,822 hours of engine testing without any failure or any significant impact on the EBC.

Summary/Conclusions

CMCs can pave the way towards an entire new dimension of using brittle ceramics in dynamic environment without fracture. CMCs when exploited for manufacturing of gas turbine blades can bring a new revolution for high temperature operation of gas turbines. This would reduce the cooling requirement of the gas turbine blades and hence increase the mass flow rate of the air coming into the gas turbine by eliminating the bleed air from compressor. This will help in providing more thrust in the engine. Engines components made of CMCs have high power to weight ratio, owing to the less weight of CMC when compared to conventional materials (nickel alloys). This could increase the overall thermal efficiency of gas turbine power plants and when implemented in all commercial aircrafts could be able to save billions in terms of fuel saving costs. Since the gas turbine is operating at higher temperature, this allows engine to operate efficiently and simultaneously reduce pollution.