Study of Materials used in Gas Turbine engine and swirler in combustion chamber

[1]Prashant Singh, Kalpit P. Kaurase[2],Gaurav Soni[3]

[1]PG Students, Mechanical Department, School of Engg. & IT.MATS UNIVERSITY Raipur, Chhattisgarh, India
[2]Asst.Prof, Aeronautical Department, School of Engg. & IT.MATS UNIVERSITY Raipur, Chhattisgarh, India
[3]UG. Student, Aeronautical Department, School of Egg. & IT.MATS UNIVERSITY Raipur, Chhattisgarh, India

Abstract

Selection of material is prime requirement during design of gas turbine engine components .due to selection of proper material can enhance the life of component .in gas turbine engine Temperature limitations is one of the most crucial limiting factors to gas turbine efficiencies and performance. At high temperature some material fails to maintain its strengths . due to varying criteria in gas turbines individual components materials selection for is one of the most difficult tasks. Also materials and alloys used for high temperatures applications are generally very costly than others. This paper is the study of various materials and their applicability for different components of gas turbine for the purpose of enhancing the performance, reliability and durability. Due to introduction of swirler in gas turbine it can effectively reduced the emissions in gas turbines. This paper presents the study of a critical review of the existing literature on gas turbine engine materials .

Keyword :- *Gas Turbine, Compressor, Turbine, Blade, Coatings,swirler***.**

---

1. Introduction

Major sources of power are obtained from coal, oil and gases. But most flexible and versatile source is crude oil which is used in almost all the places to produce the energy whether it's for mechanical, thermal or electrical. So if we consider about its effect that has been takes place on the turbine engine that particularly used in aircraft or its impact on various components of gas turbine engine, we are required to enhance or elevate in material properties that has been used nowadays. Consequently this leads us to a field of materials that contributes in building gas turbine engines with high power ratings and efficiency levels. Gas turbine engines widely used in aircraft applications as well as land based applications for producing power in contrast manner. Advancements in gas turbine materials played a vital role. i.e. with higher capability to withstand elevated temperature service, higher the engine efficiency etc. a wide variety of high performance materials-special steels and super alloys is used for construction of gas turbines. The gas turbine engine simply works on open brayton cycle in which the working fluid requires a compression, ignition, and expansion in different chambers for producing thrust.

Here is special focus on swirler used in gas turbine engine to make them more environment friendly due to significant reduction of emission and pollution and selection of proper material to increase the life span of swirler. In order to produce an expansion through a turbine a pressure ratio must be provided and the first necessary step in the cycle of a gas turbine plant must therefore be compression of the working fluid. If after compression the working fluid was to be expanded directly in the turbine, and there were no losses in either component, the power developed by the turbine would just equal that absorbed by the compressor. Thus if the two were coupled together the combination would do no more than turn itself round. But the power developed by the turbine can be increased by the addition of energy to raise the temperature of the working fluid prior to expansion. When the working fluid is air a very suitable means of doing this is by combustion of fuel in the air which has been compressed. Expansion of the hot working fluid then produces a greater power output from the turbine, so that it is able to provide a useful output in addition to driving the compressor [5] .This represents the gas turbine or internal combustion turbine in its simplest form. The three main components are a compressor, combustion chamber and turbine, connected together as shown diagrammatically in Fig.1.1 [5].

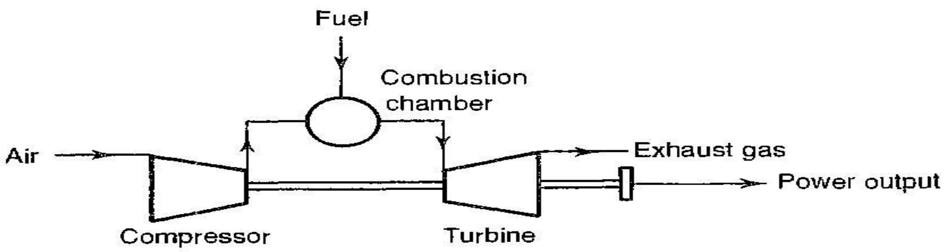
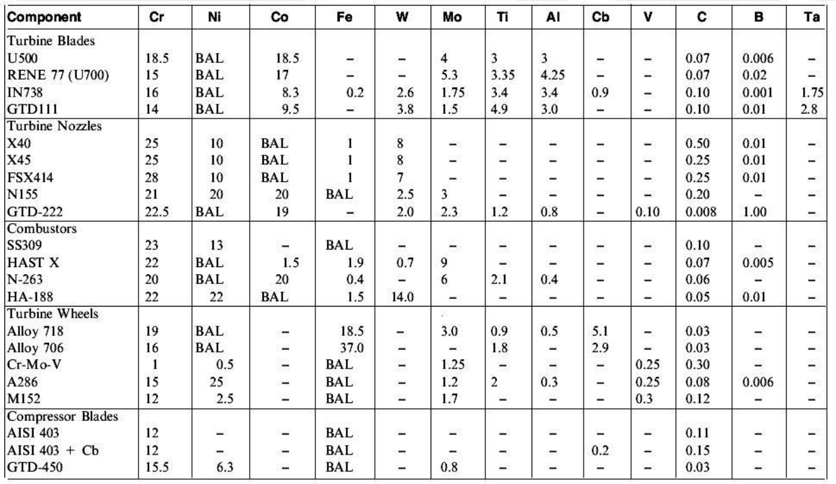


Fig.1: Simple Gas Turbine System

In the early years of turbine development, increases in blade alloy temperature from the blade alloy temperature capability accounted for the majority of the firing temperature increase until air-cooling was introduced, which decoupled firing temperature from the blade metal temperature. Also, as the metal temperature approached the 1600^0F (870 ^{0}C) range, hot corrosion of blades became more life limiting than strength until the introduction of protective coatings. During the 1980s, emphasis turned towards two major areas: improved material technology, to achieve greater blade alloy capability without sacrificing alloy corrosion resistance and advanced, highly sophisticated air Cooling technology to achieve the firing temperature capability required for the new generation of gas turbines. The use of steam cooling to further increase combined-cycle efficiencies in combustors was introduced in the mid to late 1990s.Steam cooling in blades and nozzles will be introduced in commercial operation in the year 2002 [6].The composition of the new and conventional alloys throughout the turbine is shown in the Table1.1 [6].This Table describes materials used in the high temperature turbines.



Component	Cr	Ni	Co	Fe	W	Mo	Ti	Al	Cb	V	C	B	Ta
Turbine Blades													
U500	18.5	BAL	18.5	–	–	4	3	3	–	–	0.07	0.006	–
RENE 77 (U700)	15	BAL	17	–	–	5.3	3.35	4.25	–	–	0.07	0.02	–
IN738	16	BAL	8.3	0.2	2.6	1.75	3.4	3.4	0.9	–	0.10	0.001	1.75
GTD111	14	BAL	9.5	–	3.8	1.5	4.9	3.0	–	–	0.10	0.01	2.8
Turbine Nozzles													
X40	25	10	BAL	1	8	–	–	–	–	–	0.50	0.01	–
X45	25	10	BAL	1	8	–	–	–	–	–	0.25	0.01	–
FSX414	28	10	BAL	1	7	–	–	–	–	–	0.25	0.01	–
N155	21	20	20	BAL	2.5	3	–	–	–	–	0.20	–	–
GTD-222	22.5	BAL	19	–	2.0	2.3	1.2	0.8	–	0.10	0.008	1.00	–
Combustors													
SS309	23	13	–	BAL	–	–	–	–	–	–	0.10	–	–
HAST X	22	BAL	1.5	1.9	0.7	9	–	–	–	–	0.07	0.005	–
N-263	20	BAL	20	0.4	–	6	2.1	0.4	–	–	0.06	–	–
HA-188	22	22	BAL	1.5	14.0	–	–	–	–	–	0.05	0.01	–
Turbine Wheels													
Alloy 718	19	BAL	–	18.5	–	3.0	0.9	0.5	5.1	–	0.03	–	–
Alloy 706	16	BAL	–	37.0	–	–	1.8	–	2.9	–	0.03	–	–
Cr-Mo-V	1	0.5	–	BAL	–	1.25	–	–	–	0.25	0.30	–	–
A286	15	25	–	BAL	–	1.2	2	0.3	–	0.25	0.08	0.006	–
M152	12	2.5	–	BAL	–	1.7	–	–	–	0.3	0.12	–	–
Compressor Blades													
AISI 403	12	–	–	BAL	–	–	–	–	–	–	0.11	–	–
AISI 403 + Cb	12	–	–	BAL	–	–	–	–	0.2	–	0.15	–	–
GTD-450	15.5	6.3	–	BAL	–	0.8	–	–	–	–	0.03	–	–

Table 1.1 High Temperature Alloys used in different components of Gas Turbine

2. Material used in Gas Turbine Blades:

Turbine Blades of a gas turbine engine are very prone to damage from flying debris, moreover it also sustain thermal stresses and local overheating on its surface of a gases that are coming out from combustion chambers. So use of titanium or its alloy is very meaningful because it has a great strength, durability and having such a properties that makes it useful in construction of turbine blades. Titanium is also up to 40 percent less dense than any other material giving a high enough strength to weight ratio. This means that a small quantity of it has an equal strength of a larger quantity of such a nickel or aluminum based alloy.

Application Area	Oxidation	Hot corrosion	Interdiffusion	Thermal Fatigue
Aircraft	Severe	Moderate	Severe	Severe
Land-based Power Generator	Moderate	Severe	Moderate	Light
Marine Engines	Moderate	Severe	Light	Moderate

Table 2.1: Severity of the different surface-related problems for gas turbine applications

In order to overcome these difficulties the application of advanced and modern alloys or super alloys is being introduced in aviation industries. Titanium is very easily forged and casted into various forms. Also its alloys are very resistive against corrosion and oxidation changes occurring in environment. The modern technology of manufacturing the turbine blade is also uses the alloy grain in the single crystal blade which increases its elastic properties and in turn, the natural vibration frequencies of blade can be controlled.

However, the biggest change has occurred in the nickel, where high levels of tungsten and rhenium are present. These elements are very effective in solution strengthening [b].An important recent contribution has come from the alignment of the alloy grain in the single crystal blade, which has allowed the elastic properties of the material to be controlled more closely. These properties in turn control the natural vibration frequencies of the blade [1].To achieve increased creep strength, successively higher. Levels of alloying additions (Al, Ti, Ta, Re, W) have been used to increase the levels of precipitate and substitution strengthening. However, as the level of alloying has increased the chromium additions have had to be significantly reduced to offset the increased tendency to reduce the limit ductility and reduced strength.

Reduced chromium levels also significantly reduce the corrosion resistance of the alloys. This has necessitated the development of a series of protective coating systems. The coatings are applied to provide increased component lifetimes but they often demonstrate low strain to failure properties that can impact upon the thermo mechanical fatigue endurance. Alloys have been developed with varying degrees of success, However significant work is needed in this field to develop alloy systems that address not only the alloy, but its coating. Lifting and repair as an entity not as a series of unrelated steps. There is a large Scope in industrial gas turbines for continued incremental development of Ni based alloys and coatings for the short and medium term [3].

3. Material used in Turbine Wheels:

The main functions of a turbine disc are to locate the rotor blades within the hot gas path and to transmit the power generated to the drive shaft. To avoid excessive wear, vibration and poor efficiency this must be achieved with great accuracy, whilst withstanding the thermal, vibration and centrifugal stresses imposed during operation, as well as axial loadings arising from the blade set. Creep and low cycle fatigue resistance are the principal properties controlling turbine disc life and to meet the operational parameters requires high integrity advanced materials having a balance of key properties: [3].

- High stiffness and tensile strength to ensure accurate blade location and resistance to over speed burst failure.
- High fatigue strength and resistance to crack propagation to prevent crack initiation and subsequent growth during repeated engine cycling.
- Creep strength to avoid distortion and growth at high temperature regions of the disc.
- Resistance to high temperature oxidation and hot corrosion attack and the ability to withstand fretting damage at mechanical fixings.

The stress rupture properties of this alloy are shown in figure 3.1 and 3.2 [7, 8]

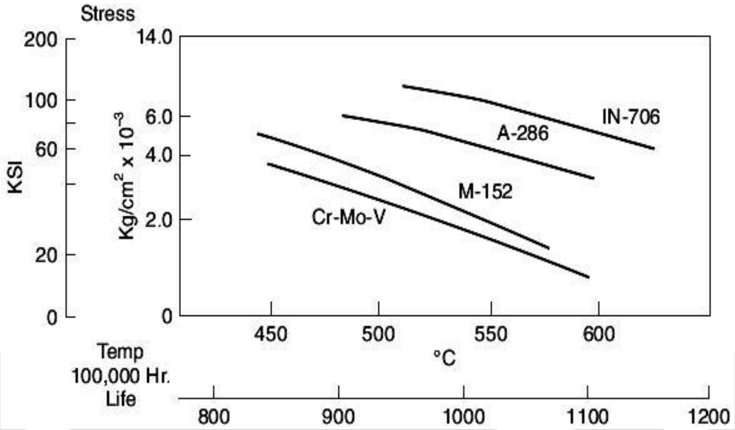


Figure3.1: Turbine Wheel Alloys stress rupture comparison

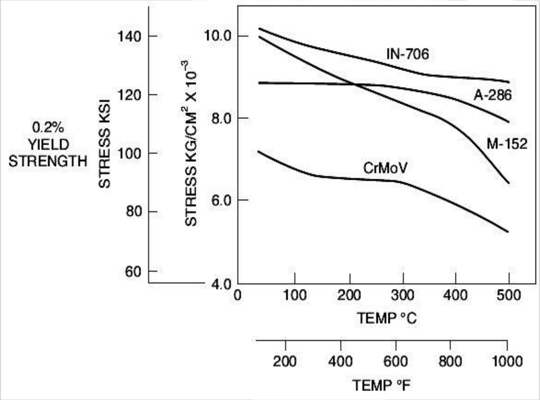


Figure 3.2: Turbine Wheel Alloys tensile yield strength Comparison

Various alloys used for turbine wheel with their short description are as follows: [6].

Alloy 718 Nickel-Based Alloy: This nickel-based, precipitation hardened alloy is the newest being developed for the next generation of frame type gas turbine machines. This alloy has been used for wheels in aircraft turbines for more than 20 years. Alloys 718 contains a high concentrations of alloying elements and is therefore difficult to produce very large ingot sizes needed for the large frame type turbine wheel and spacer forgings.

Alloy 706 Nickel-based Alloy: This nickel based, precipitation hardened alloy is being used in the large frame type units. It offers a very significant increase in stress rupture and tensile yield strength compared to the other wheel alloys.

This alloy is similar to Alloy 718, but contains somewhat lower concentrations of alloying elements, and is therefore easier to produce in the very large ingots sizes needed for the large frame type gas turbines.

Cr-Mo-V Alloy: Turbine wheels and spacers having single shaft heavy duty gas turbines are made of Cr-1%, Mo-1.25%, and V-0.25% steel. This alloy is used in the quenched and tempered condition to enhance bore toughness. Stress rupture strength of the periphery is controlled by providing extra stock at the periphery to produce a slower cooling rate during quenching.

Cr Alloys: This Category of alloys has a combination of properties that makes it especially valuable for turbine wheels. These properties include good ductility at high-strength levels, uniform properties throughout thick sections and favorable strength at temperatures up to about 9000F (4820C). Alloy M-152 is a 2-3% nickel-containing member of the 12Cr family of alloys. It features outstanding fracture toughness in addition to the properties common to other 12Cr alloys. Alloys M-152 is intermediate in rupture strength, between Cr-Mo-Vo and A286 alloy and has higher tensile strength than either one.

A286 Alloy: It is an austenitic iron base alloy that has been used for years in aircraft engine applications. Its use for industrial gas turbines started about 1965 Era, when technological advances made the production of sound ingots sufficient in size to produce these wheels possible.

Cr alloys:

These types of alloys have a combination of properties that makes it especially valuable for turbine wheels. The properties include good ductility at high strength levels, uniform properties throughout thick sections and favorable strength at temperatures up to about 900°F/482°C. M-152 alloy is a 2% to 3% nickel-containing member of the 12 Cr families of alloys. Initially, it was and still is used on the MS5002 machine as a replacement for A286. It features outstanding fracture toughness, in addition to the properties common to other 12 Cr alloys. M-152 alloy is intermediate in rupture strength, between Cr-Mo-V and A286 alloy, and has higher tensile strength than either one. (See Figure 25.) These features, together with its favorable coefficient of expansion and good fracture toughness, make the alloy attractive for use in gas turbine applications.

4. Material used in Compressor Blades:

A compressor blade is a blade machined to a precise and exacting standard to be used for application inside a turbine or compressor engine. The blades are the driving force to move air to the compression unit. The air is then forced into the tank for a compressor unit. The material that compressor blades are typically made out of are lightly weight, yet strong. A compressor blade is generally made using an alloyed metal that is able to be machined to a precision angle and dimension. Sometimes, the blades are machined out of aluminum because of the material's weight and ease of shaping. Compressor blade can also be made out of more expensive materials. This is appropriate depending on the specific application in which it will be used. A stronger and more lightweight material allows for a more stable and constant movement of as much air as possible without the blades suffering any material instability.

Compressor blading is variously made by forgings, extrusion or machining. All production blades until recently have been made from Type AISI-403 or AISI-403+Cb (both 12Cr) stainless steels. During the 1980s, a new compressor blade material, GTD-450 a precipitation hardened, martensitic stainless steel was introduced into production for advanced and updated machines as shown in Table1.1.Those material provides increased tensile strength without sacrificing stress corrosion resistance. Substantial increase in the high-cycle fatigue and corrosion fatigue strength are also achieved with this material, compared to Type AISI-403.Superior corrosion resistance is also achieved due to high concentrations of chromium and molybdenum in compressor's.Compressorbladescorrosion is usually caused by moisture and salt ingested by the turbine to avoid this coating of compressor blades is also highly recommended [6].

For small to intermediate gas turbine compressors, the temperature loadings experienced currently range from - 50 to about 500ºC. In the short to medium term the continued use of improved low-alloy and ferritic stainless steels will be adequate. This situation will continue until significant increases in compressor temperatures are needed because of much higher-pressure ratios and rotor speeds. In such a situation it is assumed that aero-derivative technology such as titanium alloys, nickel alloys and composites will be employed. This would, however, present a significant increase in cost and manufacturing complexity (forgings, machining, joining, component lifting) as well as operational difficulties (component handling, overhaul, repair, cleaning) and may introduce additional problems associated with thermal mismatch and fretting fatigue from adjoining ferritic alloys. Consideration has also been given towards lightweight materials such as aluminum matrix composites, polymer composite balding and vanes, as well as intermetallic TiAl-based alloys to provide reduced rotor and overall engine mass, and lower disc stresses to enable higher rotational speeds. In addition, design and materials concepts have evaluated the application of integrally bladed discs (bliscs) based on steel, titanium or nickel alloy technology using friction welding. Issues associated with rotor corrosion are largely operator dependent, being influenced by the specific nature of the fuel, compressor washing and cleaning practices. These are currently addressed by use of protective coatings. Likewise, commercially available abradable tip sealing coatings are currently used to provide and maintain efficiency and currently present little technical risk [3].

5. Material Used in Combustors:

The combustor tolerates the highest gas temperatures in a gas turbine and is subject to a combination of creep, pressure loading, high cycle and thermal fatigue. The materials used presently are generally wrought, sheet-formed nickel-based super alloys. These provide good thermo mechanical fatigue, creep and oxidation resistance for static parts and are formable to fairly complex shapes such as combustor barrels and transition ducts. Equally of importance is their weldability, enabling design flexibility and the potential for successive repair and overhaul operations, which is crucial to reducing life cycle. The current thermal barrier coatings technology for metallic combustor applications is based exclusively on multi-layered systems comprising of a MCrAlY bond coat and a ceramic topcoat applied using plasma spray deposition techniques. Application of this technology generally aims to limit peak metal temperatures to 900 to 950°C. Future developments are aimed at applying thicker coatings to enable higher flame temperatures and/or reduce metal temperatures further. Other programmes are aimed at increasing the phase stability and resistance to sintering of the ceramic topcoat at temperatures above 1250°C and to the inclusion of diagnostic sensor layers within the coating that enable the plant and component condition to be actively monitored [3].

The primary basis for the material changes that have been made is improvement of high temperature creep rupture strength without sacrificing the oxidation / corrosion resistance. Traditionally combustor components have been fabricated out of sheet nickel-base super alloys. Hastelloy X, a material with higher creep strength was used from 1960s to 1980s. Nimonic 263 was subsequently introduced and has still higher creep strength (Schilke, 2004). As firing temperatures further increased in the newer gas turbine models, HA-188, a cobalt base super alloy has been recently adopted for some combustion system components for improved creep rupture strength (Schilke, 2004). Coutsouradis et al. reviewed the applications of cobalt-base super alloys for combustor and other components in gas turbines (Coutsouradis et al., 1987). Nickel base super alloys 617 and 230 find wide application for combustor components (Wright & Gibbons, 2007). Table 3 gives the chemical composition of combustor materials.

Future combustor designs are aimed at replacement of conventional wrought nickel-based products with:

- Morele Nicapab-basedalloys.
- Oxide dispersion strengthen
- Ceramic matrix composites.

Grade	Chemical composition	Remarks
Hastelloy X	Ni22Cr1.5Co1.9Fe0.7W9Mo0.07C0.005B	Nickel-base super alloy
Nimonic 263	Ni20Cr20Co0.4Fe6Mo2.1Ti0.4Al0.06C	Nickel-base super alloy
HA188	Co22Cr22Ni1.5Fe14W0.05C0.01B	Cobalt-base super alloy
617	54Ni22Cr12.5Co8.5Mo1.2Al	Nickel-base super alloy
230	55Ni22Cr5Co3Fe14W2Mo0.35Al0.10C0.015B	Nickel-base super alloy; values for Co, Fe and B are upper limits.

6. Coating Materials used in Gas Turbine:

Turbine blades are individual component and often the limiting component of gas turbines. To withstand with difficulties environment turbine blades are provided with different types of coatings. The main objective of a coating is to resistance against corrosion or degradation and cracking or fatigue problems. The coating also improves the blade life for some cases almost doubles. The main requirements of a coating are to protect blades against oxidation, corrosion and cracking problems. The coating specifically thermal barrier coating allows the metal to operate cooler than normal conditions. They are used for base metal and bond coating temperature reduction on blades and vanes for improved durability. Their capabilities protect gas turbine components and increase their efficiency and reliability at higher operating temperature and under severe environmental conditions.

There are three basic types of coatings

- Aluminide (diffusion) coatings
- Overlay coatings
- Thermal barrier coatings (TBCs)

The diffusion coatings have been the most common type for environmental protection of super alloys. An outer aluminide layer (CoAl or NiAl) with an enhanced oxidation resistance is developed by the reaction of Al with the Ni/Co in the base metal. In recent years extremely thin layers of noble metals such as platinum have been used to enhance the oxidation resistance of aluminides. For most stage 1 buckets, GE used a platinum-aluminum diffusion coating until 1983 (Schilke, 2004). This coating offered superior corrosion resistance to straight aluminide coatings both in burner rig tests and in field trials. Their high temperature performance is however limited by oxidation behavior of the coatings (Schilke, 2004) . At least one of the major constituents in a diffusion coating (generally Ni) is supplied by the base metal.

An overlay coating, in contrast, has all the constituents supplied by the coating itself. The advantage is that more varied corrosion resistant compositions can be applied to optimize the performance of the coating and thickness of the coating is not limited by process considerations. The coatings are generally referred to as MCrAlY, where M stands for Ni or Co or Ni+Co. Incorporation of yttrium improves corrosion resistance. The coatings are generally applied by vacuum plasma spray process. A high temperature heat treatment is performed (1040-1120 oC) to homogenize the coating and ensure its adherence to the substrate.

The TBCs provide enough insulation for super alloys to operate at temperatures as much as 150 oC above their customary upper limit. TBCs are ceramics, based on ZrO2 – Y2O3 and produced by plasma spraying.
Ceramic coating:

The ceramic coatings use an underlay of a corrosion protective layer e.g., MCrAlY that provides the oxidation resistance and necessary roughness for top coat adherence. Failures occur by the thermal expansion mismatch between the ceramic & metallic layers and by environmental attack on the bond coat. This type of coating is used in combustion cans, transition pieces, nozzle guide vanes and also blade platforms. Improved efficiency of gas turbine engines is realized by adopting TBCs

The investigation of even more corrosion resistant coating materials has been an area of intensive research and development for the past few years. The goals of this research are to further improve the oxidation-resistance and thermal fatigue resistance of high-temperature bucket coatings. In addition to these environmentally resistant coating development efforts, work is also underway to develop advanced thermal barriers coatings for application to stationary and rotating gas path components. By careful process control, structure of these thermal barriers coatings may be made more resistant to thermal fatigue and their lives greatly extended.

Materials used for swirl vane:
Swirl vane is used for the purpose of mixing fuel and air in primary region of combustion chamber .where is atomized by the fuel injector and air comes from the outlet of compressor .with the help of swirl vane mixing take place .swirl vane is works not so high temperature as like flame tube and turbine so it can be manage without any super alloy. But at exit of compressor temperature is sufficiently high so nickel alloy is generally used .Stainless steel is also used due to good machineabilty and more strength

7. Conclusion:

Now in current scenario due increment in material cost it fairly clear that material advancement will become more prevalent in the Gas Turbine Engine industry in the future. There is some need to advance the manufacturing of material for cost reduction, increased materials performance and integrity. Due to application of advanced type of material in gas turbine engine its fatigue life will improved .and problem of hot corrosion at high temperature can also be solved by selecting of any good material another things is that problem of oxidation is occur in some material it should be avoided. Otherwise a new coating to be applied to existing materials. Design of swirler is one of complex phenomenon because it handles the variable load and heat loads. Selection of the material is one major problem in gas turbine.

8. References:

1. Miller R.A,Thermal Barrier Coatings of Aircraft Engines, History and directions,Journal of Thermal Spray Technology 1997,pp 35-42
2. N.B.Dahotre,T.S Sudarshan,Intermetallic and Ceramic Coatings,ISBN 0824799135,CRC Press.
3. J Hannis,G Mc Colvin,C J Small,J Wells,Draft of Comment,Mat UK Energy MateriaReview,Material R&D priorities for Gas Turbines based power generation,10th July 2007
4. Kurt H.Stern,Metallurgical and Ceramic Protective Coatings,ISBN 0412544407,Chapman & Hall.
5. H.I.H. Saravanamuttoo,Gordon Frederck Crichton Rogers,Henry Cohen,Gas Turbine Theory,ISBN 013015847X,Prentice Hall.
6. Meherwan P.Boyce,Gas Turbine Engineering Handbook,Second Edition,Gulf Professional Publishing,Houston,Texas
7. Bernstien H.L.,Materials Issues for users of Gas Turbine,Proceedings of the 27th Texas A&M Turbomachinery Syposium,(1998)
8. Schilke,P.W.,Advanced Gas Turbine Materials and Coatings, 39th Ge Turbine state of the Art Technology Seminar,August 1996.
9. M.P.Boyce “Advanced industrial gas turbines for power generation”Science Direct,doi.org/10.1533/9780857096180.44
10. M.P.Boyce, “An Overview of Gas Turbines Doi.Org/10.1016/B978-0-12-383842-1.00001-9