International Journal of scientific research and management (IJSRM)
||Volume||1||Issue||7 ||Pages|| 366-370||2013||
Website: www.ijsrm.in ISSN (e): 2321-3418

Advanced Materials used for different components of Gas Turbine

Shailendra Kumar Bohidar[1], Ravi Dewangan[2], Prof.Kalpit Kaurase[3]

[1]M.Tech. (Student), Mats University, Raipur
shailendrakumarbohidar@gmail.com

[2]M.Tech (Student), Mats University, Raipur
dewangan.ravi19@gmail.com

[3]Faculty, M.Tech. (Turbo machinery), Mats University, Raipur
kalpikaurase@gmail.com

Abstract*: Design of Turbo machinery is complex and efficiency is directly related to material performance, material selection is of prime importance. Temperature limitations are the most crucial limiting factors to gas turbine efficiencies. The problems at various components are of different magnitudes. As a result, the materials selection for individual components is based on varying criteria in gas turbines. Also materials and alloys for high temperatures application are very costly. This paper is focused on the study of various materials for their applicability for different components of gas turbine for increasing the performance, reliability and emissions in gas turbines. This paper presents a critical review of the existing literature of gas turbine materials. The paper will focus light on above issues and each plays an important role within the Gas Turbine Material literature and ultimately influences on planning and development practices. It is expected that this comprehensive contribution will be very beneficial to everyone involved or interested in Gas Turbines.*

Keywords: Gas Turbine, Compressor, Turbine, Blade, Coatings

1. Introduction:

High versatility and flexibility makes gas turbines to be used to produce mechanical power in case of industrial applications or thrust, when those machines are used for aeronautical purposes. The gas turbine engine is a machine delivering mechanical power using a gaseous working fluid. It is an internal combustion engine like reciprocating petrol and diesel engines with the major differences that the working fluid flows through the gas turbines continuously and not intermittently. The continuous flow of the working fluid requires the compression, heat input and expansion to take place in separate components. For that reason a gas turbine consists of several components working together and synchronized in order to achieve mechanical power or thrust[4],[5].

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].

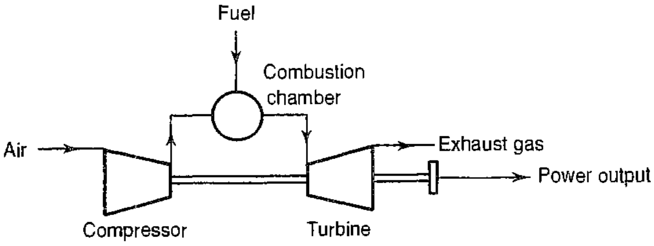
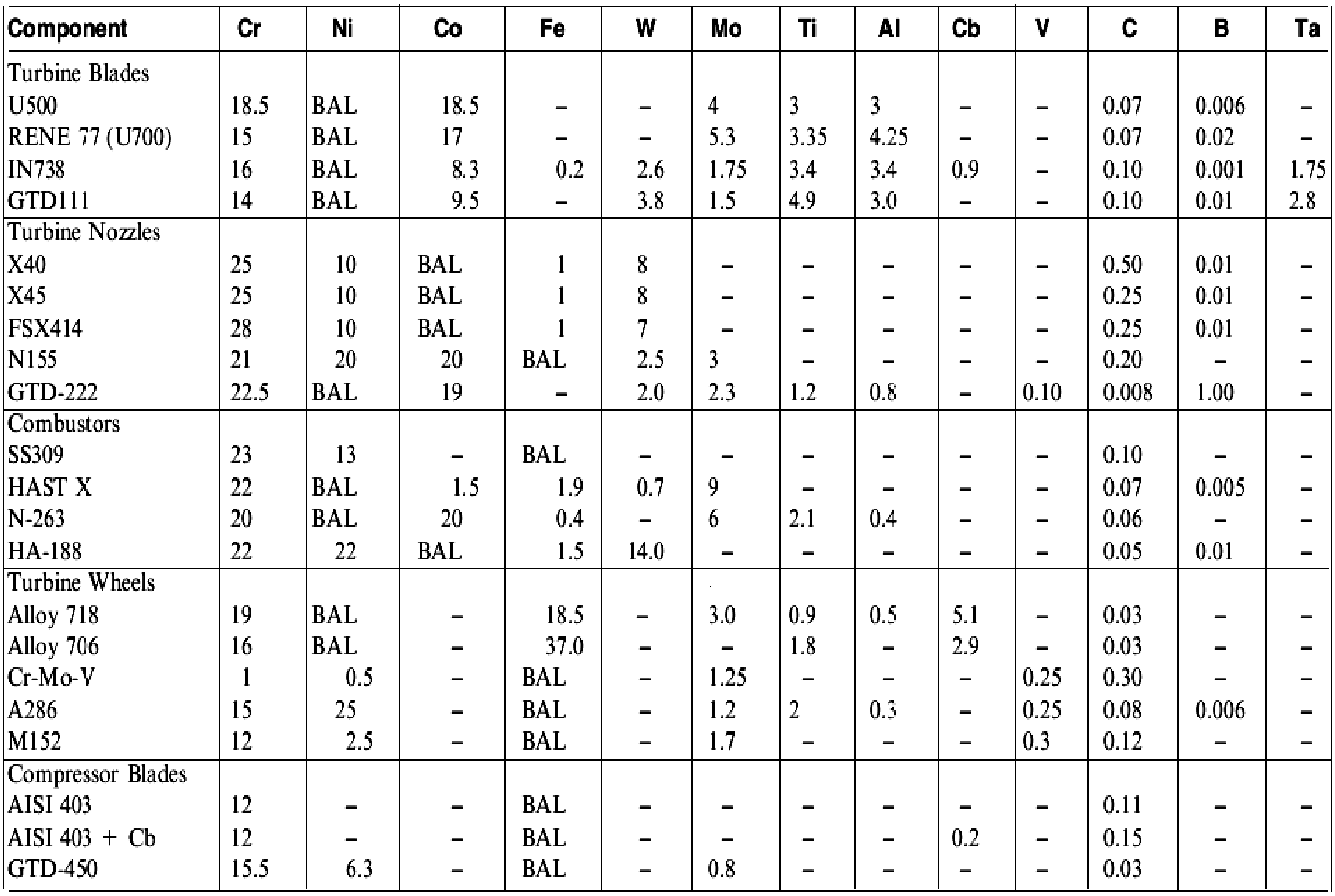


Fig.1.1 Simple Gas Turbine System

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 (870^0C) 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



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

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.

2. Material used in Gas Turbine Blades:

Turbine Blades are subjected to significant rotational and gas bending stresses at extremely high temperature, as well as severe thermo mechanical loading cycles as a consequence of normal start-up and shutdown operation and unexpected trips. The most difficult and challenging point is the one located at the turbine inlet,because,there are several difficulties associated to it like, Extreme temperature (1400^{0}C-1500^{0}C),high pressure, high rotational speed,vibration,small circulation area and so on. These effects produced in the blades are shown on the table2.1 [1].

(Effects)→ **(Applications)↓**	**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 those barriers, gas turbine blades are made using advanced materials and modern alloys (super alloys) that contains up to ten significant alloying elements, but its microstructure is very simple; consisted of rectangular blocks of stone stacked in a regular array with narrow bands of cement to hold them together. This material(cement) has been changed because in the past,intermetallic form of titanium was used in it, but now a days, it has been replaced by titanium[2].The change gave improved high temperature strength and also improved oxidation resistance.

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.lifing 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, vibrational 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]

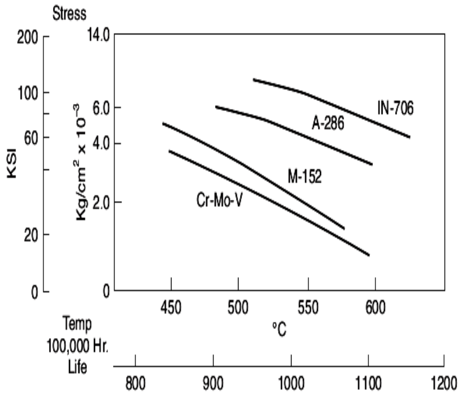


Figure3.1: Turbine Wheel Alloys stress rupture comparison

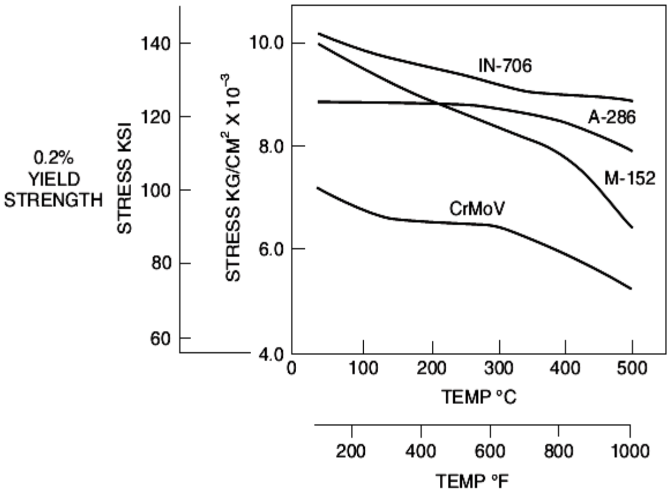


Figure 3.2 : Turbine Wheel Alloys tensile yield strength Comaprison

Various alloys used for turbine wheel with thier 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 elments 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 aloy 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%,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.
- 12Cr Alloys: This family 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 900^0F (482^0C) . 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 : A286 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.

4. Material used in Compressor Blades:

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 uprated 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 blades. Compressor corrosion 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 lifing) 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 aluminium matrix composites, polymer composite blading 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 experiences 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 superalloys. These provide good thermomechanical 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 costs. The high thermal loadings imposed often mean that large portions of the combustor hardware need to be protected using thermal barrier coatings. The current thermal barrier coatings technology for metallic combustor applications is based exclusively on multi-layered systems comprising of a MCrAlY bondcoat 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].

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

- More capable Ni-based alloys.
- Oxide dispersion strengthened metallic systems
- Ceramic matrix composites.

6. Coating Materials used in Gas Turbine:

The main requirements of a coating are to protect blades against oxidation, corrosion and cracking problems. Coatings are there to prevent the base metal from attack. Other benefits of coatings include thermal fatigue from cyclic operation, surface smoothness and erosion in compressor coatings and heat flux loading when one is considering thermal barriers. A secondary consideration but perhaps rather more relevant to thermal barriers is their ability to tolerate damage from light impacts without spalling to an unacceptable extent because of the resulting rise in the local metal temperatures. Coatings also extend life, provide protection by enduring the operational conditions and protect the blades by being sacrificial by allowing the coating to be restriped and recoated on the same base metal [6].

The main types of protective coatings used for gas turbine components can be defined as follows:

- Diffusion Coatings: Formed by the surface enrichment of an alloy with aluminium (aluminides), chromium (chromised) or silicon (siliconised). In some systems combinations of these elements are possible i.e. chrome-aluminised or silicon-aluminised.
- Overlay Coatings: Formed by applying a layer to the component surface. This type forms the bulk of the coatings used in gas turbine engines. They are applied by a variety of methods including thermal and slurry spraying, physical vapour deposition and welding. Examples include: Simple paints, corrosion resistant coatings such as MCrAlY (where M is the base metal, normally Ni or Co or a combination of the two; Cr is chromium, Alis aluminium and Y is yttrium). Thermal barrier coating based on a ceramic topcoat,usually partially stabilised cubic Zirconia, attached to the metal substrate by means of an oxidation resistant bond coat (typically a MCrAlY or a diffusion aluminide coating)).[3]

The investigation of even more corrosion-resisstant 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.

Conclusion:

Current trends such as increasing severity of process gasses and increasing material cost,make it fairly clear that material advancement will become much more prevalent in the turbomachinery industry in the future.Their may be development in advanced manufacturing for cost reduction,increased materials performance and integrity.In the short to medium term continued development of new coatings to be applied to exsisting materials will be required however in the long term as new materials are introduced coatings and their associated technologies will have to be developed as an integral part of delivering of the overall materials system solution.

References:

[01] Miller R.A,Thermal Barrier Coatings of Aircraft Engines:History and directions,Journal of Thermal Spray Technology 1997,pp 35-42

[02] N.B.Dahotre,T.S Sudarshan,Intermetallic and Ceramic Coatings,ISBN 0824799135,CRC Press.

[03] J Hannis,G Mc Colvin,C J Small,J Wells,Draft of Comment,Mat UK Energy Materials Review,Material R&D priorities for Gas Turbines based power generation,10th July 2007

[04] Kurt H.Stern,Metallurgical and Ceramic Protective Coatings,ISBN 0412544407,Chapman & Hall.

[05] H.I.H. Saravanamuttoo,Gordon Frederck Crichton Rogers,Henry Cohen,Gas Turbine Theory,ISBN 013015847X,Prentice Hall.

[06] Meherwan P.Boyce,Gas Turbine Engineering Handbook, ,Second Edition,Gulf Professional Publishing,Houston,Texas

[07] Bernstien H.L.,Materials Issues for users of Gas Turbine,Proceedings of the 27th Texas A&M Turbomachinery Syposium,(1998)

[08] Schilke,P.W.,Advanced Gas Turbine Materials and Coatings,39th Ge Turbine state of the Art Technology Seminar,August 1996.