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Aero Derivative Gas Turbine Production Materials Selection– In line with the Nigerian Industrialization Project

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Abstract-* *This is a path towards manufacturing of aero derivative gas turbine compressor, combustor, high pressure and free power turbine in Nigeria. Its materials selection is a unique, complex and desirable exercise. The major requirements of aero derivative gas turbine equipment are rigidity, corrosion resistance, light weight, safety, environmentally friendly, cost effective, availability and reliability. Various materials of Chromium, Nickel, Cobalt, Iron, Tungsten, Molybdenum, Titanium, Aluminum, Columbium (an older name for Niobium, symbol Nb), Vanadium, Carbon, Boron, Tantalum and their combination to form alloy materials were researched and computed for reference as indicated in the materials selection tables. Coating materials like titanium oxide and aluminum oxide are also added for reinforcement purpose. Ceramics matrix Composite materials were also identified as very important type of materials due to their light weight, wear, tear and temperature resistance properties. Referenced technology is LM2500 plus G5 for power generation, gas compression and ship propulsion.

Key words* *- Materials, equipment, ceramics, compression, turbines, manufacturing

I. INTRODUCTION

Nigeria is a developing Nation, rich in natural resources, with highly skilled manpower that are poorly harnessed and converted into finish product. Material science is considered a major contributor to nations industrialization effort. Aero derivative gas turbine operates under the principle of Brayton thermodynamic cycle. Operating temperatures are usually high post compressor inlet. Therefore, the need for proper material development and selection is critical for safety, equipment reliability, availability and cost efficiency. Further critical consideration for aero engine turbine design is light weight, high engine performance, high output or high thrust, low cost, high strength, high toughness and environmentally friendly materials. Numerous materials alloy composition where x trayed to determine the best fit for use grade of materials for the design and manufacturing of aero derivative gas turbine engine. Resin matrix composite materials (composite materials reinforced with high-performance fiber to achieve a high working temperature above 17000C) were also identified as critical materials for aero engine design and manufacturing. Ceramic Matrix Composite materials are classified into two. We have oxide – based and non – oxide based.

II. LITERATURE REVIEW

Swati et al (2022) presented that the aero derivative gas turbine engine is made of numerous and complex components. That these components function together to take in atmospheric air, compress it to higher temperature and pressure, mix it up with fuel and ignite same in the combustion chamber and then expand it through the turbine to produce useful work as required. Most of these components are exposed to very high temperatures and pressure as working condition, thus necessitating the need for special alloy materials to be able to provide the design requirement. The materials development has gone through various stages of research and development over the years and these explorations are progressive activities now and into the future. More than twenty-five different alloys are used to manufacture these different components, these include, but not limited to improved alloy system (steel, titanium alloys and super alloys), melting practice (air melt to vacuum induction melting, wrought forming and casting technologies etc.). Several other materials are still being explored, tested and utilized in the engine components manufacturing process and is evolving.

Quality, Light weight and high strength requirement are of paramount importance in aero derivative engine component design and manufacturing. These necessitated the magnificent budget and spending by various manufacturers on research and development to satisfy their customers and remain strong in the ever-growing aero derivative gas turbine competitive market.

Zijuan et al (2025) presented that the progressive nature of aero engine materials research and development is in line with attempt to design, manufacture and develop engine components of light weight, high engine performance and high output or high thrust. Other major targets of materials R&D are low cost, high temperature, high strength, high toughness and environmentally friendly materials. Some of the commonly used materials are the resin matrix composite materials (composite materials reinforced with high performance fiber resulting to high strength and working temperature of up to 3000 degree centigrade for the manufacturing of casings, blades, hoods, nacelles etc.), ceramic matrix composite CMC (ceramic material reinforced with high strength and high elastic fiber – reduce wear, tear and crack propagation for the production of turbine rotor and stator blades, turbine outer ring, combustion liners, turbine disk and other turbine components), high temperature alloy materials (single crystal super alloy – nickel based with continuous grain structure, no boundary, it contains refractive metals, developed up to the third generation with operating temperature of about 11500 C and directional solidification super alloy – developed by passing molten metal via temperature gradient at a controlled rate also with operating temperature of about 11500 C) and coating materials (to improve temperature resistance of engine components around the hot section, some coating materials like titanium oxide, aluminum oxide are added, thus increasing the turbine operating temperature in the hot section component 1350 C). Investment casting is used in production of aero engine components with complex structure or as desired (application of wax pattern and refractive ceramic material).

Welding technique is another method of turbine component manufacturing. About fifty percent of turbine components are manufactured by the application of welding technique. This is applicable in both new parts manufacturing and repair or maintenance work. Most turbine engine manufacturing companies invest heavily in welding technique research and development to improve the basic requirement of turbine engine components – light weight, high strength, quality, and maneuverability.

George & Konstantinos (2023) presented that materials selection for aero engine reflect both thermodynamics and mechanical properties requirement. Ceramics Composite Matrix (CMC) materials possess these outstanding qualities to withstand high temperature and mechanical load specifications according to aero engine design. They also have the properties of lesser weight and high efficiency. CMC materials could be oxide – based or non – oxide based.

The oxidation resistant CMCs materials are classified as oxide based and are used in oxidizing environment like turbine engine hot section (exhaust). Alumina and aluminosilicate fall into this category. The aforementioned two materials are combined with various ceramics, metallic fillers and reinforcement to form these oxide CMC materials. It therefore implies that alumina and aluminosilicate are the based materials for oxide CMCs. Alumina can be combined with boron carbide, silicon nitride, titanium dioxide filler to produce a reinforced material of oxide CMC with better creep and corrosion resistance properties compared to non – oxidizing CMC materials.

Non – oxide CMC has better thermal and mechanical properties compared to oxide base CMC materials. Non – oxide base CMC materials are composed of non – oxide base ceramic materials, a filler and reinforcement – ceramic, metallic, plastic, polymer etc. The lows of non – oxide CMC are poor oxidation and corrosion resistance, especially when exposed to high temperature. There is a standard for aero engine materials called Aerospace Materials Specification (AMS), which govern materials used for aerospace

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engine manufacturing, but no single standard for aero derivative gas turbine engine manufacturing. It involves various specialize materials depending on requirements. These requirements include, but not limited to high strength, durability, stiffness, low density, high thermal stability, high corrosion resistance and oxide resistance. Aero engine manufacturers are interested in materials elastic limit and stiffness (mechanical properties) and thermal expansion coefficient (thermal properties). The turbine combustion section is manufactured with non – oxide CMC materials, while the exhaust section is manufactured with oxide CMC materials.

III. MATERIAL SELECTION

Selection of materials for aero engine components design and manufacturing is a critical stage in the preliminary design process. Important considerations are light weight, high engine performance, high output or high thrust, low cost, high temperature, high strength, high toughness and environmentally friendly materials. Resin matrix composite materials (composite materials reinforced with high-performance fiber to achieve a working temperature of more than 1700C for the manufacturing of casings, blades, hoods, nacelles etc.). Ceramic matrix composite CMC are ceramic material reinforced with high strength and high elastic fiber to achieve lesser components wear, tear and crack propagation for the production of turbine rotor and stator blades, turbine outer ring, combustion liners, turbine disk and other turbine components). High temperature alloy materials and directional solidification super alloy are developed by passing molten metal via temperature gradient at a controlled rate and coating materials (to improve temperature resistance of engine components around the hot section, some coating materials like titanium oxide, aluminum oxide are added, thus increasing the turbine operating temperature in the hot section component). Investment casting is used in production of aero engine components with complex structure or as desired (application of wax pattern and refractive ceramic material). Welding technique is another method of turbine component manufacturing. About 50% of turbine components are manufactured by the application of welding technique. This is applicable in both new parts manufacturing and repair or maintenance work (Zijuan, 2025).

Ceramic Matrix Composite materials are of oxide – based and non – oxide based. The oxidation resistant CMCs materials are the as oxide based, used in oxidizing environment like turbine engine exhaust. Alumina and aluminosilicate fall into this category. Alumina and aluminosilicate are combined with various ceramics, metallic fillers and reinforcement to form these oxide CMC materials. Alumina is combined with boron carbide, silicon nitride, titanium dioxide filler to produce a reinforced material of oxide CMC with reasonable creep and corrosion resistance properties. The Non – oxide CMC are used when better thermal and mechanical properties are required, they are composed of non – oxide base ceramic materials, a filler and reinforcement – ceramic, metallic, plastic, polymer etc. Cautiousness is required during the application of non – oxide CMC materials due to poor oxidation and corrosion resistance, when exposed to high temperature. The turbine combustion section is manufactured with non – oxide CMC materials, while the exhaust section is manufactured with oxide CMC materials (Konstantinos & George, 2023). The major interests in this thesis are but not limited to high strength, durability, stiffness, low density, high thermal stability, high corrosion resistance and oxide resistance. See tables 3.1, 3.2, 3.3, 3.4 and 3.5 indicating various components and chemical composition of alloy materials for aero engine design and manufacturing.

Table 3.1: Materials selection for aero derivative gas turbine blades (Shailendra, 2013)

Material	Cr	Ni	Co	Fe	W	Mo	Ti	AI	Cb	V	C	B	Ta
U500	18.5	BAL	18.5	0	0	4	3	3	0	0	0.07	0.006	0
RENE77(U700)	15	BAL	17	0	0	5.3	3.35	4.2	0	0	0.07	0.02	0
IN738	16	BAL	8.3	0.2	2.6	1.75	3.4	3.4	0.9	0	0.10	0.001	1.75
GTD111	14	BAL	9.5	0	3.8	1.5	4.9	3.0	0	0	0.10	0.01	2.8

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Table 3.2: Materials selection for aero derivative gas turbine nozzles (Shailendra, 2013)

Material	Cr	Ni	Co	Fe	W	Mo	Ti	AI	Cb	V	C	B	Ta
X40	25	10	BAL	1	8	0	0	0	0	0	0.50	0.01	0
X45	25	10	BAL	1	8	0	0	0	0	0	0.25	0.01	0
FSX414	28	10	BAL	1	7	0	0	0	0	0	0.25	0.01	0
N155	21	20	20	BAL	2.5	3	0	0	0	0	0.20	0	0
GTD-222	22.5	BAL	19	0	2.0	2.3	1.2	0.8	0	0.10	0.008	1.00	0

Table 3.3: Materials selection for aero derivative gas turbine combustor (Shailendra, 2013)

Material	Cr	Ni	Co	Fe	W	Mo	Ti	AI	Cb	V	C	B	Ta
SS309	23	13	0	BAL	0	0	0	0	0	0	0.10	0	0
HAST X	22	BAL	1.5	1.9	0.7	9	0	0	0	0	0.07	0.005	0
N-263	20	BAL	20	0.4	0	6	2.1	0.4	0	0	0.06	0	0
HA-188	22	22	BAL	1.5	14.0	0	0	0	0	0	0.05	0.01	0

Table 3.4: Materials selection for aero derivative gas turbine wheels (Shailendra, 2013)

Material	Cr	Ni	Co	Fe	W	Mo	Ti	AI	Cb	V	C	B	Ta
Alloy 718	19	BAL	0	18.5	0	3.0	0.9	0.5	5.1	0	0.03	0	0
												0	
Alloy 706	16	BAL	0	37.0	0	0	1.8	0	2.9	0	0.03		0
												0	0
Cr-Mo-V	1	0.5	0	BAL	0	1.25	0	0	0	0.25	0.30		
A286	15	25	0	BAL	0	1.2	2	0.3	0	0.25	0.08	0.006	0
M152	12	2.5	0	BAL	0	1.7	0	0	0	0.3	012	0	0

Table 3.5: Materials selection for aero derivative gas turbine compressor blades (Shailendra, 2013)

Material	Cr	Ni	Co	Fe	W	Mo	Ti	AI	Cb	V	C	B	Ta
AISI 403	12	0	0	BAL	0	0	0	0	0	0	0.11	0	0
												0	
AISI 403 + Cb	12	0	0	BAL	0	0	0	0	0.2	0	0.15		0
												0	
GTD-450	15.5	6.3	0	BAL	0	0.8	0	0	0	0	0.03		0

IV. CONCLUSION

Aero derivative gas turbine materials were selected for compressor blades, turbine blades, turbine nozzles, turbine combustor, turbine wheels, exhaust, gas generator casing, turbine casing, bellmouth etc. Thus, material requirement for the three major components of compressor, combustor and turbines was thoroughly addressed. It should be noted that aero engine materials development is an ever-evolving critical section of design process. This is necessitated by the need to design and manufacture more reliable, cost efficient and environmentally friendly equipment. It is very important at this time for developing Nation like Nigeria to intentionally progress into innovative, productive, impactful materials science maturity to aid its local and international application.

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