Comprehensive report on Materials for Gas Turbine Engine Components

Anushraj B, Winowlin Jappes J T, Adam Khan M, Dillibabu V and Brintha N C

Abstract: ***In the past three decades, it is very challenging for the researchers to design and development a best gas turbine engine component. Engine component has to face different operating conditions at different working environments. Nickel based superalloys are the best material to design turbine components. Inconel 718, Inconel 617, Hastelloy, Monel and Udimet are the common material used for turbine components. Directional solidification is one of the conventional casting routes followed to develop turbine blades. It is also reported that the raw materials are heat treated / age hardened to enrich the desired properties of the material implementation. Accordingly they are highly susceptible to mechanical and thermal stresses while operating. The hot section of the turbine components will experience repeated thermal stress. The halides in the combination of sulfur, chlorides and vanadate are deposited as molten salt on the surface of the turbine blade. On prolonged exposure the surface of the turbine blade starts to peel as an oxide scale. Microscopic images are the supportive results to compare the surface morphology after complete oxidation / corrosion studies. The spectroscopic results are useful to identify the elemental analysis over oxides formed. The predominant oxides observed are NiO, Cr2O3, Fe2O3 and NiCr2O4. These oxides are vulnerable on prolonged exposure and according to PB ratio the passivation are very less. In recent research, the invention on nickel based superalloys turbine blades produced through other advanced manufacturing process is also compared. A summary was made through comparing the conventional material and advanced materials performance of turbine blade material for high temperature performance.***

Keywords: nickel, corrosion, oxide, SEM, EDS, XRD

I. INTRODUCTION

Gas turbine engine component has to face severe working temperature [1]. Nickel based superalloys of different grade are used for gas turbine engine components [2]. In general the nickel based superalloys are stable at elevated temperature for oxidation/ corrosion for certain duration.

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Due to this characteristic the metal is used for high temperature application [4].Basically superalloys are FCC in structure [5]. The applications of superalloys with their properties of different grade are explained by Matthew & Stephen [6] and George [7].

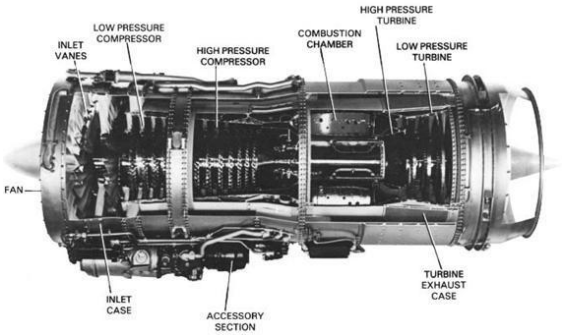

Fig 1: Cross of Section of Light Combat Aircraft – Gas Turbine Engine. [3]

II. ADDITIVE MANUFACTURING MATERIALS

Recently, research on additive manufacturing process has been adopted to manufacture gas turbine engine components. Juillet et al [8] made an attempt to develop IN718 a nickel based superalloy. Investigations are made to compare the forged component and additive manufactured component with reference to the formation of Cr_2O_3 scale. Moussaoui et al [9] investigated on selective laser melting (SLM) of IN718 to study the effect of porosity effect of the alloy. The micro hardness of the SLM manufactured component is increased with the effect of heat treatment. Chongliang Zhong et al [10] Compares IN718 and IN625 superalloys are manufactured by additive manufacturing the deposition rate of laser metal deposition. The material deposition is good for IN 718 when compared to IN625. Bonny Onuike et al [11] compares thermal properties of IN 718 and bimetal of copper and IN 718 manufactured by additive manufacturing. The thermal diffusivity and conductivity is increased for pure IN718. Mario Valdez et al [12] developed IN 718 superalloy through laser based additive manufacturing. The complex shapes are easily produced in short period of time. In powder bed fusion method the process parameter are highly influencing the component microstructure. By reducing scan speed and hatch distance and increase the laser power increase the density of the material. The dense additively manufactured component has less porosity.

The dense additively manufactured component has less porosity. It was found that density of material is good then it gives good tensile strength and impact strength.

Built direction of laser based AM are shown in figure 2. It infers the microstructure of the samples at different direction and orientation [13]. Lin Zhu et al [14] reported the laser based AM process and its properties for IN718. The laser solid forming treatment with solution treated samples of different age conditions are compared. It was reported that HA samples gives good strength and microhardness at the same samples manufactured at 1350W laser power gives fine grain. Xing Li et al [15] made an attempt to study the heat treatment of DSLM produced samples. It has reported that solution plus ageing sample obtained higher volume of fraction which improves the hardness of the material. Tiana et .al [16] comparison of annealed and age hardened & two step aged hardened of laser powder deposition alloy was investigated. The author reported that in annealed and age hardened alloy gives good tensile strength at both ambient and elevated temperatures. The Li et al [17] explains the importance of the heat treatment of SLM manufactured components. The material manufactured by SLM cannot be used as it manufactured since the material will have columnar grain, porosity and undesired properties. The material should undergo heat treatment process to get desired grain size, reduces porosity, improve the density and tensile strength.

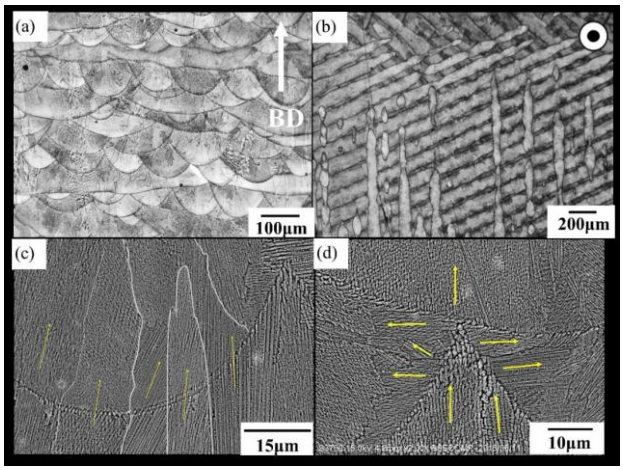

Fig. 2: MPB microstructures of the as-built specimen: (a) side view and (b) top view [13].

Konecna et al [18] compared the SLM manufactured over conventional by manufactured IN718 alloy to report the crack growth of the alloy on mechanical condition. Probstle et al [19] treated SLM alloy have high creep strength when compared to wrought material. Kuo et al [20] revealed that the direct aged SLM component of IN718 have improved creep strength when compared to wrought material. Strano et al [21] claimed that surface roughness of SLM component is affected by the parameter like laser power, hatch distance, scanning speed, part geometry and scanning strategy.

III. CORROSION IN GAS TURBINE ENGINE

Gurrappa et al [22] compares the single crystal nickel based alloy with IN 792 and CMSX 4 superalloys. It was reported that single crystal nickel alloy founds to be the best to resist sulfur and chlorine reactions during combustion of the engine at elevated temperature. Gonzalez et al [23] performed corrosion studies on heat resistant alloys with two different molten salts. Corrosion starts from the chromium depletion on the external surface in the form of oxides. The internal corrosion may happen due to the form of sulfate. T.S.Sidhu et al [24] made an attempt on molten salt corrosion of nickel coated alloy at 900˚C. During combustion V_2O_5 and Na_2So_4 are deposit on the surface of the surface of the material. Chromium and silicon oxides offer better hot corrosion due to their slow growth and act as barrier for ionic implantation.

Saber et al [25] made a study on high temperature cyclic oxidation on nickel alloys. The investigation is made at different operating temperatures to report change in mass during exposure and its kinetics. The Cr_2O_3, NiO and $NiCr_2O_4$ are protective layer developed on prolonged exposure of the alloy. It is due to the internal and external oxide elements migration. The thickness of oxide layer found increasing with time and operating condition.

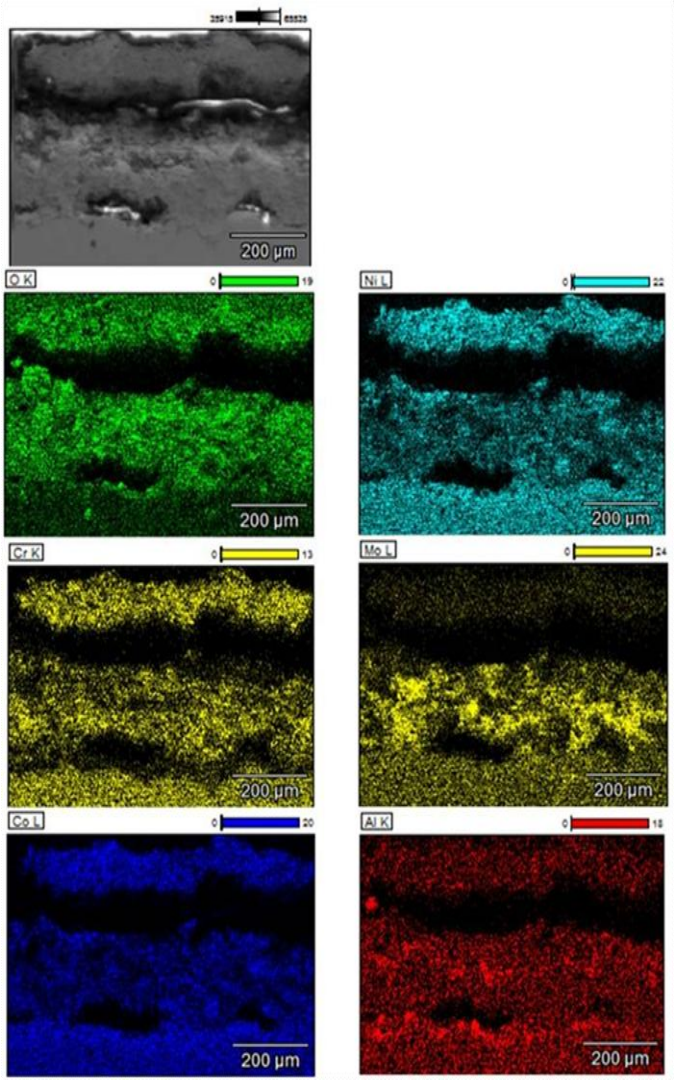

Fig 3: Electron image and X – ray scan image mapping of NiCr – Cr2O3 coated sample exposed at 1000°C. [2]

IV. TENSILE STRENGTH IN GAS TURBINE MATERIAL

Demetriou et al [28] investigated age hardening alloy and reported how the grain growth of different prime phase is attained. At the same age hardening in nickel alloy and its strengthen are compared. It improves the tensile strength of the nickel alloy. Noguchi et al [29] reported that the cyclic fatigue of superalloy is not only affected by age hardened materials. There is slight difference in the age hardened and non aged hardened materials. Similarly the tensile strength of non-age hardened material has good strength when compared to age hardened material. And there is slight difference in 1000hr age hardened and 5000hr age hardened for 700˚C materials. Enxiang Pu et al [30] investigated mechanical and metallurgical properties of solution treated nickel based alloy. The report on grain growth and grain size are observed that the solutionizing temperature will increase the grain growth and reduced on exposure. The tensile ductility and work hardening component (n) was increased and tensile strength and strain hardening rate is reduced while the increasing grain growth of the material. Y.C. Lin et al [31] investigated on work hardening of superalloy can be achieved by solutionizing cooling process. With raise in temperature the size of γ″ phase rapidly decreases. Li-ming TAN et al [32] reported that the increasing the chromium, cobalt, tungsten and Molybdenum content the tensile strength is improved. Demetriou et al [28] investigated age hardening alloy and reported how the grain growth of different prime phase is attained. At the same age hardening in nickel alloy and its strengthen are compared. It improves the tensile strength of the nickel alloy. Noguchi et al [29] reported that the cyclic fatigue of superalloy is not only affected by age hardened materials. There is slight difference in the age hardened and non aged hardened materials. Similarly the tensile strength of non-age hardened material has good strength when compared to age hardened material. And there is slight difference in 1000hr age hardened and 5000hr age hardened for 700˚C materials. Enxiang Pu et al [30] investigated mechanical and metallurgical properties of solution treated nickel based alloy. The report on grain growth and grain size are observed that the solutionizing temperature will increase the grain growth and reduced on exposure. The tensile ductility and work hardening component (n) was increased and tensile strength and strain hardening rate is reduced while the increasing grain growth of the material. Y.C. Lin et al [31] investigated on work hardening of superalloy can be achieved by solutionizing cooling process. With raise in temperature the size of γ″ phase rapidly decreases. Li-ming TAN et al [32] reported that the increasing the chromium, cobalt, tungsten and Molybdenum content the tensile strength is improved.

V. SUMMARY

- Nickel based superalloys are used in gas turbine application. They are single crystal austenitic structure with good mechanical properties has supported to high temperature applications. However, they are prone to corrode on prolonged exposure at different operating conditions such as molten salt, temperature and time.
- To increase the stability, superalloys are heat treated / age hardened. At majority samples are coated with thermal barrier coatings to resist corrosion and oxidation. During high temperature exposure, the scale formed with protective metallic / intermetallic oxides are also extending the surface from cyclic corrosion.
- Additive manufacturing is a recent technique adopted to produce turbine engine components. Inherently, the mechanical properties are superior when compared commercial alloys.

  Therefore, it is confirmed that the additive manufacturing process can be adopted to develop the turbine component. At the same the heat treatment can be proposed to enrich the mechanical and metallurgical quality of the sample.

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