A Review on Microstructure and Mechanical Properties of L-PBF 17-4PH and 15-5PH SS

I. Kartikeya Sarma, N. Selvraj, and A. Kumar

Abstract Additive manufacturing made a revolution in the Manufacturing area by producing parts with less lead time and highest complexity. It creates parts in layer by layer manner using engineering design. Metallic components in all fields can be produced by Additive manufacturing because of its near net shape production and high quality production. Many Steels can be processed using Additive manufacturing methods. 17-4PH and 15-5 PH Stainless Steels are the precipitated hardened steels which exhibits better mechanical properties after Heat treatment. Even though so many Additive manufacturing Processes are there, Selective Laser Melting gives fully dense and quality parts. In this review paper, we have given an over view on the Microstructure, mechanical, corrosion properties and fatigue properties of 17-4 PH SS and 15-5 PH SS produced by SLM and comparison with conventional parts.

Keywords Precipitation hardening · Solution annealing · Aging

1 Introduction

Additive manufacturing involves manufacturing of parts in a layer by layer manner which is generated from 3D CAD data. The main advantages of Additive manufacturing is that it produces near net shapes with extreme complexity and less lead time compared to conventional manufacturing processes. This made Additive manufacturing parts to use for medical implants, aerospace components, chemical and petrochemical applications, surgical instruments and general metal working applications [1–50]. The material that is commonly used in this application is 17-4 PH SS.

Among additive manufacturing, selective laser melting (SLM) is one of the processes to produce metal parts. Each layer is deposited by repeated melting and fusion of thin layer of the powder with previously deposited and fused layer with the

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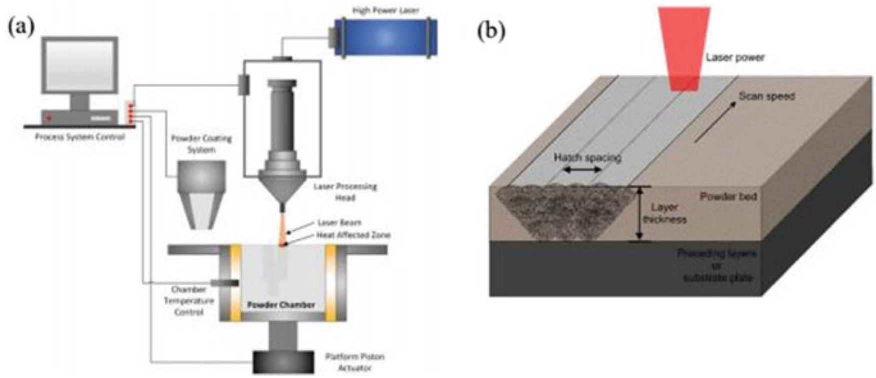

Fig. 1 **a** Operating procedure of LPB process, **b** close view of LPB process [38]

help of High Power Laser to build entire part. Selective Laser Melting Process gives high density and quality parts when compared to other processes [1–20] (Fig. 1).

1.1 About 17-4 PH SS

The considerable amount of price and good processability of steels are the reasons for them to use in Additive Manufacturing. Among the various stainless steel precipitated hardened steels has drawn attention. Among precipitated steels, 17-4 Precipitation Hardened Stainless Steel has drawn most attention because of its good mechanical and corrosion properties. It has high tensile strength, fracture toughness, impact toughness and corrosion potential up to 300 °C. Martensite phase is dominant in this kind of steel so it is used in applications in the fields of power plants, powder injection moulding industries, Marine environment. 17-4 PH SS applications in defense and aerospace industries are engine stator parts, Compressor impeller, Fasteners and Fitting gears because of its combined high hardness and strength. It also high corrosion resistance so it is used in oil and gas industry [1–23].

After solution heat treatment and quenching, martensite phase appears when we see microstructure. After aging for a temperature of 480–620 °C the strengthening occurs due to more copper precipitates in the martensite matrix and this precipitates hinders dislocation motion [18]. This steel is susceptible to hydrogen embrittlement [16]. They are promising to Production of AM parts because of its good weldability [26].

17-4PH Stainless Steel consists of chromium with a range of 15–17.5%, Ni and Cu each of 3–5% [25]. Nickel is the austenitic stabilizer. Both higher chromium content and nickel helps to have higher corrosion Potential. Due to Cu rich precipitates Precipitation Hardening occurs, which nucleate and grow during aging heat treatment (Table 1).

Table 1 Commercial chemical composition of 17-4 precipitation hardened SS

Chemical composition	Iron (Fe)	Cr	Ni	Cu	Si	Mn	Ni
% balance	Bal	17.5–15	5–3	5–3	<1.0	<1.0	0.45–0.15

1.2 Applications of 17-4 PH SS

The Applications of 17-4 Precipitation Hardened Stainless Steel are there in so many fields [1–17, 21–38] like

- Structural parts in aerospace applications
- Hand tools in Biomedical Applications
- Gate Valves
- Food Process Equipment
- Chemical Processing
- Mechanical Components
- Nuclear Waste Processing
- Storage -dry cask
- Foils, Helicopter Deck Platforms, etc. in oil and gas industry
- Paper Mill Equipment in Paper and Pulp industry
- Marine-Process Piping, seawater piping, and Heat Exchangers.

1.3 Scope of This Review Paper and Organization of This Article

In this review article, our focus is to present the review of microstructure, mechanical, fatigue and corrosion Properties of Stainless steel type of L-PBF 17-4 PH. Within this article there are subsections where effect of Heat Treatments like Solution Annealing, Aging on microstructure, Hardness, Energy Density, Wear properties, Corrosion Properties and Fatigue Properties are discussed.

In this review article 15-5 PH's Microstructure, Mechanical, Wear, Corrosion and Fatigue properties are also discussed after discussion of 17-4 PH SS within one section. Within that subsection the precipitation Hardening Principle and the 15-5 PH material Properties are discussed.

2 Methods and Discussion of Stainless Steel Type of 17-4 Precipitation Hardened

2.1 *Microstructure and Texture of Stainless Steel Type of 17-4 Precipitation Hardened*

Extensive studies have been performed on the SLM 17-4 PH SS to understand influence of atomizing media, scan strategy, Different Process Variables like Defocus Distance, Scan speed, Laser Power, Hatch Distance on density, microstructure and surface roughness was investigated [1–17, 21–23, 40–47].

This materials wrought alloy has fully martensite structure [26]. Martensitic structure for this alloy is slightly above the room temperature. Retained austenite also possible due to Ni as austenitic stabilizer.

Rashid et al. [2] reported that martensite and austenite both present in the fabricated samples while Paolo Leo et al. has reported grains are mixed and equiaxed. They have seen rich nano sized spherical inclusions in Mn, Si and O which are about 33 nm [8] while Luiz carneiroa et al. have reported that there are pores due to entrapment of gas.

The XRD patterns of both Water Atomized parts and Gas Atomized parts are having solely martensite and mixture of martensite and austenite phases. The grain size also decreased as the energy density decreased except for gas atomized parts [44].

Adeyami [48] reported the influence of Laser Power on LMD 17-4 PH using 316L substrate. He studied by depositing the samples by laser tracks. He varied Laser power between 1.0 and 2.6 KW with fixed Scan Speed at 1.2 m/s, fixed rate of powder flow 5 g/min and fixed rate of gas flow 2 l/min. The microstructure was dendritic and less δ-ferrite at less laser power while coarser and high δ-ferrite seen at high laser power.

From all these studies, we can conclude that the microstructure of the as- fabricated samples consists of austenite and martensite while some pores resulted because of entrapment of gas.

2.2 *Microstructure and Texture of Stainless Steel Type 17-4 Precipitation Hardened After Heat Treatment*

Rashid et al. [2] reported that retained austenite and martensite after heat treatment some studies has shown that martensite percentage changed after solution annealing and aging.

Sun et al. [6] reported that after solution annealing there is no change in microstructure but after aging (H 900 condition) martensite block size changed to 2.9 μm, average grain size and FCC volume fraction was also abruptly changed. For the wrought alloy also there is no change in microstructure after solution annealing and aging.

Both TEM and EBSD analysis indicated that with oxide inclusions grain boundary migration happened after Heat treatment in SLM sample, which results in more refined grains structure than solution Heat treated wrought sample [6]. The lath size is up to 30 μm with martensite block sizes around 8 μm in As built Sample Compared to Wrought alloy.

Sun et al. [22] reported the influence of Heat Treatment on the mechanical properties and microstructure of SLM 17-4 precipitation Hardened steel and wrought alloy. He reported the effect of solution annealing Heat Treatment for 4 h 1038 °C and quenching, the martensitic structure was obtained. The samples have solutionized and aged, then the apparent microstructure obtained in AM has no differences in wrought samples. The initial microstructure also does not has any impact on Cu rich precipitation during aging Heat Treatment.

Cheruvatur [47] reported the effect of stress relieving on the wrought and AM 17-4 PH SS. He found that stress relieving for 1 h has no impact on microstructure. Even for wrought material it is insufficient to alleviate the segregation of microstructure.

From all these studies, we can conclude that the martensite and retained austenite was obtained after completion of Heat treatment some studies has shown that martensite percentage changed after solution annealing and aging.

2.3 Effect of Fabrication Environment and Atomizing Media on 17-4 PH SS Properties

Some authors investigated influence of Atomizing media on the mechanical properties and powder characteristics of 17-4 Precipitation Hardened SS [3, 9, 27–29, 45]. The atomizing media is either water atomized or gas atomized and fabrication atmosphere is either argon or nitrogen atmosphere. The microstructure is martensitic in case of argon atmosphere and austenitic in nitrogen atmosphere and 6% martensitic. The thermal conductivity of nitrogen is more so the phase content difference is 40% which helps in faster cooling rates.

The fabrication atmosphere also has impact on phases of 17-4 PH SS microstructure. In nitrogen atmosphere the retained austenite was 50–75% and in case of argon atmosphere the austenite was 8%.

At energy density 104 J/mm^3 and post processed at 1315C and aged at 482C the tensile strength has improved and comparable with gas atomized UTS and YS and wrought alloy. Hardness increased as the energy density improved [3].

Heat treatment at 1315 °C and aging at 482 °C for gas atomized powder given small (30–40 nm) and large (>100 nm) enriched Cu- precipitates. The water atomized powder parts revealed fine (30 nm) enriched Cu rich precipitates distributed uniformly in BCC martensitic structure [3].

Irrinki [44] reported about the Mechanical properties of As- Fabricated Water Atomized parts are higher than As Fabricated Gas Atomized parts and conventional 17-4PH SS parts.

From all the studies, we can conclude that the fabrication atmosphere also has impact on phases of 17-4 PH SS microstructure.

2.4 Porosity and Density

The effect of defocus distance on porosity was less at medium defocus distance [1]. Rashid et al. investigated the density of sample is almost 100% and compared fabricated sample with the 3D CAD model by 3D CT Scan.

Hu [19] and Spierings [50, 51] reported the influence of scan speed and some more process variables on Density and porosity. He found that the medium scan speed giving higher denser sample because of complete melting of the sample and zero pores in the sample. As scan velocity increases the pore size will be more, the insufficient melting and balling phenomenon occur.

Somayeah pasebhani et al. reported that carbon composition is less in Gas Atomized Powder than Water Atomized Powder [3]. Paolo Leo et al. reported the defects arise due to voids resulted from aluminum oxide and unfused powder. The shape of these defects is irregular and average diameter is greater than 20microns. Fractional Area of the defects is <0.52% [5].

Irrinki [44] investigated that the Density is almost same for both water and gas atomized 17-4 PH SS L-PBF parts in as fabricated condition.

All the studies conclude that the medium scan speed giving higher denser sample because of complete melting of the sample and zero pores in the sample.

2.5 Effect of Powder Reuse

Zapico [39] investigated the morphology, chemical characteristics and microstructure of the 17-4 PH Stainless Steel after 10 and 20 manufacturing reuses. He found that EDS analysis of the powder showed that with the reuse the chemical composition was changed and higher oxide concentrations were appeared about 15 m. Moreover the XRD analysis showed increase of austenite phase with the reuse of powder which depends on the fabrication chamber atmosphere. From all the studies, we can conclude that by reusing powder, the powder properties influence the density and surface roughness of the produced part.

2.6 The Influence of Spatter Particles on Mechanical Properties

Usman [45] reported about formation of oversized (185 μm) and undersized (125 μm) spatter particles during L-PBF. The crystallographic phases, size, morphology, chemical composition and microstructure of the spatter particles also studied. The influence of the spatter particles on density, surface roughness and tensile strength of L-PBF samples were also studied. The size of undersized and oversized particles are higher than original powder. Original powder and US particles are dominated by spherical particles and oversized are dominated by spherical agglomerates.

The fusion, partially sintered spatter and satellite particles are the types of OS spatter particles. The original powder and under sized spatter particles showed equiaxed Microstructure but oversized spatter particles showed finer equiaxed Microstructure. The cause is potential nucleation sites increase resulted from adhesion of semisolid particles from oversized Spatter Particles.

Surface Roughness increased in Spatter rich parts and non spatter rich parts to 28 and 15% for cylindrical and tensile parts. The curved surface of cylindrical parts has made increase in surface roughness to 60% than flat tensile parts. Spatter rich parts have higher porosity than the non spatter rich parts. Spatter rich parts have higher porosity than the non spatter rich parts.

2.7 Effect of HT on Properties of 17-4 PH SS

2.7.1 Effect of Heat Treatment on Micro- hardness

Ponnusamy et al. [1] reported that at medium defocus distance the micro hardness was higher due to higher density and defect free component of as fabricated samples. He also reported good surface finish for the medium defocus distance samples.

Rashid et al. had reported that double scan strategy giving highest Hardness compared to single scan strategy as the laser remelts the deposited sample [2].

Most of the researchers reported that by Aging Heat Treatment, the Hardness was higher and samples are isotropic due to martensite and precipitation of Cu rich particles [4–18]. Stress relieving also reported that the Hardness was increased slightly when compared to as fabricated sample [4].

The porosity increased with energy density for PBF steels. The Vickers Hardness obtained was highest at 53.3 GJ/mm^3 and residual stresses are higher than casting steel for PBF steels.

Stress relieving for 1 h improved the hardness for SLM 17-4 Precipitation Hardened SS material [47].

From the above studies, we can conclude that the medium defocus distance and double scan Strategy gives the Highest Hardness. By Aging Heat Treatment, the

Hardness was higher and samples are isotropic due to martensite and precipitation of Cu rich particles. Stress relieving also reported that the Hardness was increased slightly when compared to as fabricated sample.

2.7.2 Effect of Heat Treatment on Elongation and Yield Strength

Heat treatment samples have lower elongation and higher yield strength compared to as built samples. It is because of change in composition, quantity and size of precipitation strengthening phases. The Heat treated and as built samples having ductile rupture [8, 9] while tensile strength is independent of part location on the build plate and also on powder reuse [11].

The Yield Strength increased and elongation decreased for the as built samples after completion of Heat treatment. This is because of change in chemical composition, quantity and size of precipitation strengthening phases. The fracture surfaces correspond to ductile fracture and tensile strength does not depend on type of build plate and powder usage after re manufacturing.

Yadallohi reported that elongation is less in vertical direction compared to horizontal direction. Plastic strains are also less compared to elastic strains for both Heat treated and as fabricated samples.

Michela et al. [16] reported about tension tests performed in air with temperature maintained at room temperature for both notched and smooth specimens for both SLM and wrought steels and aging for 4 h at 580 °C. The elongation is around 21–26% for smooth specimens for both wrought and SLM steels. The strength of SLM ferritic steel is 100 MPa lesser than wrought martensitic steel.

Flippo nalli reported the calibration of three ductile damage models of EBM Ti6Al4V and SLM 17-4 PH SS. He made a series of samples for performing mechanical characterization in static mode. He made round smooth specimens, notched specimens, testing under plane starin condition and torsion test specimens. Stress rate at critical pints are seen by FEM simulation and data collected by hybrid Experimentation and compared with damaged models.

From all the studies, we can conclude Heat treatment samples have lower elongation and higher yield strength compared to as built samples. It is because of change in composition, quantity and size of precipitation strengthening phases. The Heat treated and as built samples having ductile rupture.

2.7.3 Effect of Heat Treatment on Wear Strength of 17-4 PH SS

KC [14] investigated the wear rate is less for LP-PBF 17-4PH SS samples than Conventionally 17-4 PH SS in lubricated condition because of difference in surface roughness. As hardness is high for LP-PBF Parts so less wear rate will be there because of difference in surface roughness in these samples. The dominant wear mechanism is Adhesion during dry testing condition. The wear mechanisms surface fatigue and abrasion are dominant in lubricated condition for both SLM and Wrought Samples.

Shibata et al. [15] investigated the wear and friction properties under oil lubrication of laser PBF stainless steels in oil lubrication in 5 different conditions by changing the scan speed and laser power for Casting Steel. The friction coefficient increased gradually from initial stage and then become constant for both SLM and wrought material. Wear rate increases with coefficient of friction for entire period.

Friction coefficient increased with normal load from initial stage. Then it is gradually increased. The mean friction coefficient and specific wear rates increases with normal loading. The PBF steels wear rates are lesser than wrought steels.

The specific wear rates also increased with mean friction coefficient during entire period. The mean friction coefficient and specific wear rates of PBF Steels are lesser than Casting steel for all the conditions.

From all the above studies, we can conclude that Wear rate is less for L-PBF 17-4Precipiation Hardened Stainless Steel samples than Conventionally 17-4 PH SS in lubricated condition because of higher Surface Roughness.

2.7.4 Influence of Heat Treatment on Corrosion Properties of 17-4 Precipitation Hardened Stainless Steel

Michela et al. [16] reported the influence of hydrogen embrittlement is less when solution annealed than peak aging but the susceptibility decreases as the solution annealed temperature increases. Both SLM and wrought steels are influenced to Hydrogen Embrittelement with slower displacement rates. Fracture elongation was decreased with uncharged steels. SLM steels exhibit higher Hydrogen Embrittlement compared to Wrought Steels because of grain size and crack propagation and initiation was more easy in SLM ferritic steel than wrought martensitic steel.

Michella [17] reported the corrosion resistance and microstructure of SLM and wrought 17-4 PH Stainless steel. SLM as built Steel samples consists of ferrite only. After Reaustenitingmartensite was observed. The corrosion resistance of both as built and reasustenized samples have same corrosion resistance which is related to chemical composition. The martensitic reaustenized samples have more corrosion resistance than martensitic wrought samples because of MnS inclusions. The microstructure difference has little impact on corrosion resistance. The grain boundary and density pitting potential of As built sample greater than reaustenized parts.

From other corrosion studies also [27, 30] we can conclude that the corrosion potential of AM (even for both gas and water atomized parts) is better than the wrought parts. Better corrosion resistance for AM parts is due to its refined microstructure, inclusions, increased stability of passive film in case of nitrogen content when parts are fabricated in nitrogen atmosphere.

From all the studies, we can conclude that Corrosion potential of 17-4 Precipitation Hardened Stainless Steel (even for both gas and water atomized parts) is better than the wrought parts.

2.7.5 Effect of Heat Treatment on Fatigue Properties of 17-4 PH SS

Several studies were there on the fatigue behavior of 17-4 Precipitation Hardened Stainless Steel [9–13, 29, 46] and there are studies about fatigue crack growth behavior in both parallel and perpendicular direction. Those samples tested in parallel orientation have shorter fatigue life compared to perpendicular direction because of internal defects. The internal defects become large defect area compared to gage area, they become crack initiation sites.

Both the heat treatments solution annealing and aging did not improve the fatigue potential of 17-4 Precipitation Hardened Stainless Steel [13] while Yadollahi et al. [9] reported that the effect of HT to fatigue cracking growth was not there but the build direction of the sample showed much impact on fatigue behavior of LP-PBF samples. Large delamination observed in cracking growth direction of specimens with transverse cracking in both as fabricated and HT specimens.

He [10] also reported from fatigue test results, HT is beneficial for low cycle fatigue and but not for high cycle fatigue. Stress concentration is more in vertical direction as more area is exposed to loading. Cracks were there near surface of specimens from smaller voids due to unmelted regions in long life testing. Multiple Crack initiations were found near the surface in short life testing due to smaller voids.

Soltani-Tehrani [11] investigated the impact of re use of powder and part location on the fatigue properties. The fatigue behavior for LP-PBF metal parts with influence of powder reuse and part location on the build plate was insensitive. But the fatigue behavior of the metal parts in machined surface state was dependent on build plates part location and effect is decreasing.

Mower [46] investigated the mechanical behavior of SLM AlSi10Mg, DMLS Ti6Al4V, DMLS 17-4 PH and 316L. The fatigue strength of SLM AlSi10Mg, DMLS Ti6Al4V is inferior as that of conventional material. This is due to multiple cracks developed during cyclic loading at defects region. While fatigue strength of DMLS17-4 PH and 316L is almost same as that of conventional material. Fatigue fractures developed prematurely before the loading.

From all the above studies, we can conclude that Samples tested in parallel direction have shorter fatigue life compared to perpendicular direction because of internal defects. Fatigue test results showed that the heat treatment will only benefit low cycle fatigue but not high cycle fatigue. The fatigue properties of 17-4 PH parts with the with the variation of part location on build plate and reuse of powder was insensitive in as fabricated condition.

Table 2 Chemical composition of 15-5 PH SS

Composition of 15-5 PH SS	Fe	Cr	Ni	Cu	Nb	Mn	Si
% balance	75	15	5	4	<0.1	<0.1	0.15–0.45

3 AM of 15-5 PH Stainless Steel

3.1 About 15-5 PH SS

Because of high strength, ductility and mechanical properties 15-5 PH is used in aerospace industries. This martensitic precipitation hardened steel mechanical properties and corrosion potential is improved by Heat treatment and by adding alloys.

Transformation of BCC ferrite Phase to FCC austenite phase when we heat above A3 temperature. To transform austenite back to Ferrite by cooling back and by carbon dissolving in FCC structure will form Cementite. When this steel is rapidly cooled, carbon atoms diffuse from the FCC phase of austenite to BCC but it does not happen. Highly strained BCT crystal forms which is known as martensite. Cooling rapidly makes carbon atoms to diffuse from austenite FCC phase to BCC but it does not happen and highly strained BCT martensite phase forms.

Shear Deformation formed by dislocations of carbon atoms makes the strength improved. Without heat treatment the ductility and strength are good but the strength increases by Heat Treatment.

15-5 PH Stainless Steel consists of Cu, Ni, Cr, Fe. Addition of Mn, Nb and Si giving benefit [39] (Table 2).

By quenching the both ductility and strength improved but it is lesser for usable value and helps for machining addition of 4% Cu after quenching makes Cu to trap in crystal structure and over saturates. Over saturating is removed by steel heating to an medium temperature then Cu becomes precipitated. It is known as Precipitation Hardening.

Increasing the temperature of steel makes Cu traps in crystal structure and produce fine particles, dislocations and improvement of strength.

3.2 Methods and Discussion of 15-5 PH SS

Several studies [18–20, 31–37, 49] reported the production of Laser PBF SLM 15-5 PH stainless steel. The influence of build direction on basic mechanical and fatigue properties were investigated and properties of AM 15-5 PH SS compared with wrought Stainless Steel. Influence of Solution Annealing and Aging on this particular steel and wrought alloy were also discussed [18–20].

Roberts [37] given that the high temperature tensile strength of AM Samples are about 30% more than wrought parts and Vickers Hardness of AM samples are 50% more than its wrought parts. Stress Rupture Tests at 211 MPa and 593 °C had shown that AM parts have 30% more rupture life than conventional parts.

Jun et al. [18] reported the influence of process variables on thermal gradient which directly affects the mechanical properties and microstructure. He also given the influence of build direction and heat treatment on the mechanical properties and microstructure. The mechanical properties and microstructure of as fabricated, solution annealing and aging, aging, solution annealing and conventionally manufactured parts were investigated. The micro structure has ferrite, martensite plus austenite. Both Solidification and Heat gradient made the formation of retained austenite and rapid cooling rates giving precipitation hardening by aging with solution HT. Hardness in horizontal direction had given high hardness than vertical except for aging. Anisotropy is common. Solution annealing parts have less hardness than other (as fabricated, aging, CM and S and A).Hardness of SLM parts are higher than CM because of rapid cooling in AM parts.

Nath et al. [19] reported on the influence of HT on microstructure, corrosion, wear and mechanical properties of 15-5PH SS parts made by SLM process. The influence of microstructure on corrosion and mechanical properties were analyzed. H900 Aging made increase in Hardness, yield strength and corrosion resistance through Cu rich Precipitates. Brittle nature made wear rate increase and decrease of impact energy. (H1150) made the specimen ductile, lesser yield strength, Low Hardness and wear and high impact energy. Solution annealing reduced anisotropy by microstructure Homogenization. Aging at high temperature and long soaking time made an impact on mechanical properties and decrease corrosion properties. Solution Annealing before Aging gives Homogenized microstructure.

Wang et al. [20] investigated the microstructural optimization for Heat treated SLM 15-5PH Stainless Steel to enhance corrosion resistance was investigated. The results showed that after aging treatment, Cu rich nanoparticles (about 10 nm) diffusely precipitated, and approximately 18–25% austenite was distributed near the molten pool boundary. The surface potential of the austenite was approximately 15 mV higher than that of martensite by scanning Kelvin probe force microscopy. However, the austenite phase disappeared and the new NbC-(Mn, Si) O duplex particles precipitated after Aging and Solution Annealing, which decreased the pitting Corrosion Potential and passive stability of film for the SLM 15-5PH stainless steel.

Nong et al. [41] reported the mechanical Properties and microstructure of the SLM15-5 PH SS and wrought SS. He found that the YS and UTS were higher compared to wrought alloy while elongation was less compared to wrought alloy. The as built sample has large volume of austenite. The austenite after retained was greatly reduced by Heat treatment and completely transformed into martensite which leads into improvement of mechanical properties. Strength and micro hardness was improved by fine grain microstructure and concentration of dislocations.

Alafaghani [49] reported the Mechanical properties and Microstructure of SLM IN 718 and SLM 15-5 PH. He made the tensile testing at three different temperatures (RT, 200 °C, 450 °C) and three different directions X, Y, Z. The microstructure was observed by using Fry's agent and observed with help of SEM and OM. SEM images was seen for checking powder particle size and porosity. There was no permanent change in microstructure but there was change in microstructure in different directions. Reduction in tensile properties was there with increase in temperature. Anisotophy reduced with increase in temperature.

From all the above studies, we can conclude that High temperature tensile strength of 15-4 PH SS AM Samples are about 30% more than wrought parts and Vickers Hardness of AM samples are 50% more than its wrought parts. Solution Annealing parts have less hardness than other heat treatment processes (As Fabricated, Aging and Solution annealing and Aging).Hardness of 15-5 PH SS AM parts are higher than CM because of rapid cooling in AM parts.

Aging done after completion of Solution Annealing is recommended for the homogeneity in microstructure for 15-5 PH SS AM parts. Wear and Corrosion Potential of Additive Manufactured Parts are more than Conventional Parts.

4 Summary

In this paper previous study of 17-4 PH SS and 15-5 PH SS made by laser-PBF were reviewed. The influence of heat treatment on mechanical properties like Hardness, Tensile behavior, yielding, Elongation, Wear strength, Corrosion Resistance, Fatigue properties and microstructure of both 17-4 PH SS and 15-5 PH SS made by Laser-PBF were discussed. The effect of powder reuse and Spatter Particles on the Mechanical Properties was also discussed.

Despite so many advantages of L-PBF there are some disadvantages like re melting, solidification and rapid melting of the powder during production of parts, complex microstructure. These disadvantages hamper wide applications. In future so many heat treatment procedures needed to be applied to understand the microstructure. To meet the industrial demands the influence of Heat Treatment on Wear, Corrosion, Fatigue Properties and Complex Microstructure to be studied more deeply.

Summary Table

S. No.	Material	Type of study	Conclusion
01	17-4 PH SS	Microstructure and texture before heat treatment	Microstructure of the as- fabricated samples consists of austenite and martensite while some pores resulted because of entrapment of gas
02	17-4 PH SS	Microstructure and texture after heat treatment	Martensite and retained austenite was obtained after completion of Heat Treatment some studies has shown that martensite percentage changed after solution annealing and aging

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(continued)

S. No.	Material	Type of study	Conclusion
03	17-4 PH SS	Effect of fabrication environment and atomizing media	Fabrication atmosphere also has impact on phases of 17-4 PH SS microstructure
04	17-4 PH SS	Effect of porosity and density	Medium scan speed giving higher denser sample because of complete melting of the sample and zero pores in the sample
05	17-4 PH SS	Effect of powder reuse	By reusing powder, the powder properties influence the density and surface roughness of the produced part
06	17-4 PH SS	Effect of heat treatment on micro hardness	By aging heat treatment, the hardness was higher and samples are isotropic due to martensite and precipitation of Cu rich particles. Stress relieving also reported that the Hardness was increased slightly when compared to as fabricated sample
07	17-4 PH SS	Effect of heat treatment on yield strength and elongation	Heat treatment samples have lower elongation and higher yield strength compared to as built samples
08	17-4 PH SS	Effect of heat treatment on wear strength	Wear rate is less for L-PBF 17-4 precipitation hardened stainless steel samples than conventionally 17-4 PH SS in lubricated condition because of higher surface roughness
09	17-4 PH SS	Influence of heat treatment on corrosion properties	Corrosion potential of 17-4 precipitation hardened stainless steel (even for both gas and water atomized parts) is better than the wrought parts
10	17-4 PH SS	Effect of heat treatment on fatigue properties	Heat treatment will only benefit low cycle fatigue but not high cycle fatigue. The fatigue properties of 17-4 PH parts with the with the variation of part location on build plate and reuse of powder was insensitive in as fabricated condition
11	15-5 PH SS	Effect of heat treatment on all properties of 15-5 PH SS SLM	Aging done after completion of solution annealing is recommended for the homogeneity in microstructure for 15-5 PH SS AM parts. Wear and corrosion potential of additive manufactured parts are more than conventional parts

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