Manufacturing of Udimet using Powder Bed Fusion and Evaluation of its Mechanical Properties

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ABSTRACT

Udimet is a superalloy which possesses exceptional strength, corrosion resistance, and high-temperature stability in which they are primarily used in applications where materials must withstand extreme environments, such as in the aerospace, automotive, and energy industries. Casting and forging are the conventional metallurgical processing techniques that can be used to manufacture superalloys. Here, udimet alloy is being produced using one among the most versatile additive manufacturing processes, laser powder bed fusion. The manufacturing method referred to as Laser Powder Bed Fusion (LPBF) involves building three-dimensional components out of successive layers of material in which it enables the production of intricate geometries and patterns that are challenging or impossible to produce using conventional manufacturing techniques. By utilising laser energy, this particular type of additive manufacturing technique selectively melts and fuses metal powder into solid objects. This paper's goal is to give a general overview of the udimet alloy, which is made using a laser powder bed fusion process, as well as to summarise its key process parameters, mechanical properties, and metallurgical flaws and potential control strategies, all of which directly affect its mechanical properties.

Keywords*:* Udimet, Laser powder bed fusion, Mechanical properties

1 Introduction

Superalloys are a group of high-performance alloys that exhibit exceptional strength, corrosion resistance, and thermal stability at high temperatures. They are primarily used in applications where they must perform reliably under extreme conditions, such as in gas turbine engines, nuclear reactors, and other high-temperature and high-stress environments. The term "superalloy" typically refers to a class of alloys that have been specifically designed to withstand temperatures above 540°C (1004°F). At these temperatures, most conventional alloys would either deform or fail due to thermal expansion or oxidation [1]. Superalloys, on the other hand, maintain their mechanical strength and resistance to creep, corrosion, and oxidation even at extremely high temperatures [2]. Superalloys are usually composed of a base metal, such as nickel, cobalt, or iron, to which various elements are added to enhance its performance properties. These elements may include chromium, aluminium, titanium, tungsten, molybdenum, and others. To obtain the right combination of elevated temperature strength, anti-corrosion properties, and other qualities, the alloying elements must be carefully chosen and matched. In addition to their mechanical and corrosion resistance properties, superalloys can also exhibit other unique characteristics, such as shape memory and high damping capacity. These characteristics make them perfect for a variety of applications, including aircraft, power generating, medicinal devices, and sporting equipment. Their unique combination of properties makes them one of the most advanced classes of materials available today.

Conventional processes used to manufacture super alloys are casting and forging. Wax casting, also known as investment casting or lost wax casting, is a widely used method for manufacturing superalloy components with complex shapes and fine details. The udimet alloy, which is made using the laser powder bed fusion

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technique, is described in this work along with a summary of its major process parameters, mechanical characteristics, and metallurgical flaws and a possible enhancement strategy.

The term "Laser Powder Bed Fusion" refers to a particular additive manufacturing technique for metals [3]. Laser Powder Bed Fusion of Udimet involves selectively melting metal powder using a high-powered laser to create complex 3D parts. A small coating of metal powder is first applied to a substrate, and then, using a computer-aided design (CAD) file as a guide, a laser beam is used to melt the powder where it is needed. Layer by layer, the procedure is continued until the last section is constructed. The process allows the creation of parts with high accuracy, excellent surface finish, and complex geometries [4]. LPBF can produce Udimet parts with excellent mechanical properties, making it ideal for applications in aerospace, energy, and other demanding industries.

In terms of design flexibility, waste reduction, shortened lead times, customisation, and better material qualities, LPBF provides a number of benefits over conventional production procedures. Because to these benefits, LPBF is a desirable alternative for several applications across numerous sectors [5].

2 Materials Used

The material used in this study is udimet; which is a nickel-based superalloy. Udimet is renowned for its superior mechanical and high-temperature strength. These superalloys are made to function effectively in harsh environment with corrosive and oxidising conditions, as well as high temperatures and pressures. Udimet superalloys are renowned for their outstanding fatigue resistance, which makes them perfect for use in cyclic loading applications. These properties complement their high-temperature strength and corrosion resistance. The composition of udimet is given below in table 1.

Table 1: *Composition of Udimet*

Element	Content (%)
Nickel	55.45
Chromium	18
Cobalt	14.70
Titanium	5
Molybdenum	3
Aluminium	2.50
Tungsten	1.25
Zirconium	0.030
Boron	0.033
Carbon	0.035

Nickel, cobalt, chromium, aluminium, titanium, and other elements are included in the composition of udimet super alloys. To obtain certain material qualities like high strength, toughness, and resistance to creep, oxidation, and corrosion, these elements are carefully chosen and matched. Advanced metallurgical processes like vacuum melting, powder metallurgy, or directed solidification are frequently used to create udimet superalloys. By minimising flaws and impurities that can weaken the material, these techniques assist to assure uniformity and consistency in the material's qualities.

Udimet super alloys are a popular option for a variety of demanding applications in sectors including aerospace, power generation, and chemical processing because of their superior mechanical and high-temperature capabilities.

Nickel (Ni): Nickel is the primary component of Udimet alloys and provides high-temperature strength and corrosion resistance.

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Cobalt (Co): Udimet materials are enhanced with cobalt to increase its creep resistance and extreme temperature strength.

Chromium (Cr): Chromium is a key component of Udimet alloys and provides corrosion resistance and high-temperature strength.

Molybdenum (Mo): Udimet alloys benefit from the addition of molybdenum by having greater tensile and high-temperature properties.

Tungsten (W): The Udimet alloys' key compound, tungsten, offer high-temperature strength, resistant to wear, and resistance to corrosion.

Aluminium (Al): Aluminium is added to Udimet alloys to improve their oxidation resistance at high temperatures.

Titanium (Ti): Udimet alloys are strengthened at elevated temperatures and have better creep resistance by the addition of titanium.

Carbon (C): To increase the strength and hardness of Udimet alloys at high temperatures, carbon is added.

Other elements: Udimet alloys may also contain small amounts of other elements, such as boron, copper, iron, silicon, and sulphur, depending on the specific grade and its intended use.

Udimet alloys are frequently used in gas turbine engines, where they are put through a lot of stress and heat. Udimet 720 is utilised in combustion liners and other hot section components, whereas Udimet 500 is frequently employed in turbine blades and discs.

Udimet alloys are designed to withstand extreme temperatures and environments, while maintaining high strength and corrosion resistance. The specific composition of each grade is carefully optimized to achieve these properties, and may vary depending on the intended application.

3 LPBF Process of Udimet

A powerful laser is used in the additive manufacturing technique known as laser powder bed fusion (LPBF) to melt and fuse metallic powders layer by layer to produce three-dimensional objects. The proposed LPBF method relies on an iterative approach to create fragments in a powder bed over layers. After the coater has applied a layer of powder to a flat surface, one or more laser beams are directed over the areas that will melt and solidify to form a single layer of the additively manufactured parts [6]. The process involves the following steps:

- Pre-processing: The first step in LPBF is pre-processing, which involves preparing the digital model of the object to be manufactured. This model is typically created using computer-aided design (CAD) software and converted into a format that can be read by the LPBF machine.
- Powder preparation: The metallic powders used in LPBF must be carefully selected and prepared to ensure high quality and consistency. The powders must have a uniform particle size distribution and be free of contaminants that could affect the properties of the final object.
- Preparation of the build platform: The first step in LPBF process is to prepare the build platform. The build platform is typically made of a heat-resistant material, such as aluminum or titanium. To keep the merged object from clinging to the platform, it has to be thoroughly cleaned and then treated with a release agent.

- Powder spreading: A thin layer of metallic powder is spread evenly across the build platform using a re-coater blade. The thickness of this layer is typically between 20 and 100 microns, depending on the specific LPBF machine and the properties of the powder.
- Laser scanning: The metallic powder layer is next scanned with a strong laser beam, melting and fusing the powder particles to create a solid layer. A computer program accurately controls the laser beam to produce the required form. To ensure excellent melting and bonding of the powder particles, the laser parameters, including power, speed, and focus, must be properly optimized.
- Layer by layer building: Following a brief descent of the build platform, usually between 20 and 100 microns, a fresh coating of metallic powder is applied on top of the one that was previously present. The laser beam is again used to scan and fuse the powder particles 12 together to form a new layer. This process is repeated layer by layer until the final object is complete. The LPBF machine uses the digital model of the object to determine the shape and position of each layer.

To build a 3D cross-section of the completed object, a laser beam melts specific area in each layer. As a result, the building platform beneath is lowered. The powder coater/wiper mechanism is then used to add another layer of powder. Up to the construction of the three-dimensional solid object, this cycle is successively repeated [7]. A schematic representation of the lpbf process is shown in figure 1.

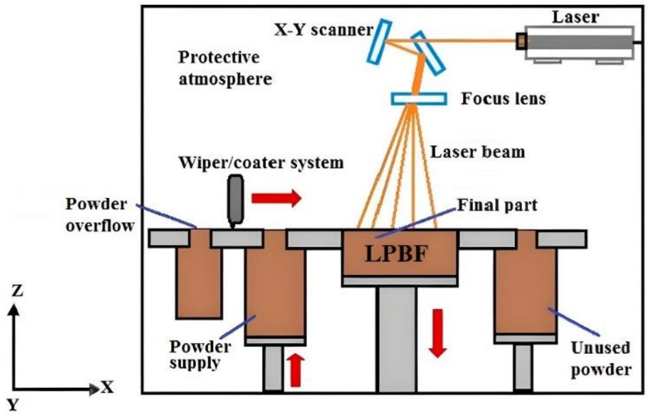

Figure 1: *Schematic Diagram of LPBF Process*

Compared to traditional manufacturing methods, LPBF has a number of benefits, such as the capacity to create complex geometry and shapes and the ability to make products with a high degree of precision and accuracy. LPBF also allows for the use of a wide range of metallic powders, including superalloys, which are difficult to process using conventional methods. Although LPBF machine designs differ between machine manufacturers, the fundamental operating principles and machine architecture are constant. The manufactured sample for testing is shown in figure 2 below. The sample's dimension is 10mm in diameter and 40mm in length.

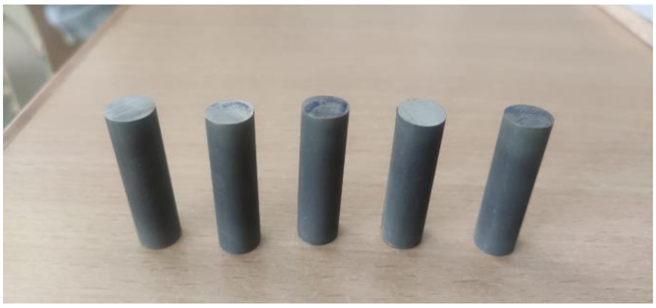

Figure 2: *Manufactured sample*

4 Formation of Metallurgical Defects and their Control Methods

During the LPBF process, metallurgical flaws such as balling, porosities, oxidation, and residual stresses are frequently observed [8].

4.1 Balling

When molten metal powder does not properly fuse together, a process known as "balling" occurs, leaving tiny balls or spheres on the surface of the printed product. The primary influences on this phenomenon are the material's density, viscosity, and surface tension. Surface tension and capillary forces work together to induce the molten pool to shrink into its lower surface energy state, which is spherical, when the creation of individual melt tracks results in poor contact with the substrate below. Surface roughness, porosity, low density, uneven melt tracks are the main effects of balling [9].

For preventing balling, laser re-melting of the molten metal is found effective. Similar to this, heating the baseplate beforehand can improve how easily liquid metal flows over the substrate. Balling can have an adverse impact on the mechanical qualities, as well as the quality and integrity, of the printed product. A careful control of the printing settings and optimisation of the powder bed composition and preparation are necessary to reduce balling in LPBF.

4.2 Porosity

In laser powder bed fusion (LPBF) additive manufacturing procedures, porosity is a frequent source of concern. A solid substance is said to be porous if it has voids or empty areas. Porosity in LPBF can be brought on by a number of reasons, including: incomplete melting of powder particles, gas entrapment, insufficient powder spreading, low metal powder compactness etc. If the laser beam does not provide enough energy to fully melt the powder particles, the resulting solid material may have voids, which results in incomplete melting of powder particles. During the melting process, gas can become trapped within the molten material, which also leads to porosity. Another reason is that if the powder is not spread evenly, there may be regions with a lower density of powder particles, leading to porosity [10].

Porosity can significantly affect the final part's mechanical characteristics by lowering its strength and raising its susceptibility to failure. Therefore, LPBF must consider minimising porosity. Substrate preheating and using laser re-melting are methods for reducing porosity. Throughout the LPBF process, it is thought to be advantageous to choose the right process parameters that will result in an acceptable amount of liquid metal and a longer molten metal pool lifespan.

4.3 Oxidation

The environment of the LPBF processing chamber is essential for producing components without oxides. Despite the fact that the working chamber's oxygen content is constrained by a shielding inert gas flow and protective inert surroundings. There is always a potential of a tiny percentage of undesirable oxygen content being present during the LPBF process.

This is because of the tiny amount of air that exists in between the powder particles. Thick oxide inclusions limit the flowability of molten pools, restrict the absorption of laser energy, and intensify the effects of surface tension.

The use of clean, dry powders is required to reduce oxidation while still maintaining a low enough oxygen partial pressure. Ensuring a suitable build environment, using high-quality powder with low oxygen concentration, and optimising laser settings to cut down on the amount of time the molten material is exposed to the atmosphere are all crucial steps in lowering the danger of oxidation in LPBF. In order to lessen the effects of oxidation and enhance the mechanical qualities of the finished product, post-processing methods like hot isostatic pressing (HIP) or heat treatment can also be utilised [11].

4.4 Residual stresses

Residual stresses can develop in the component throughout the LPBF process for a number of reasons, including heat cycling, phase changes, and solidification. The performance and characteristics of the component might be significantly impacted by residual stresses in LPBF. These may result in cracking, distorting, and a shorter fatigue life. To assure the quality and dependability of the finished product, it is crucial to comprehend and manage residual stresses in LPBF. Optimizing process parameters, preheating the substrate, and post-processing treatments like heat treatment or shot peening are just a few of the measures that may be used to reduce residual stresses in LPBF [12].

5 Mechanical Properties

5.1 Hardness Test

The resistance of a metal to plastic deformation is measured by its hardness. Hardness test is to be carried out using Vickers hardness test machine. It is based on the principle of creating an indentation in the surface of the material using a diamond indenter, and then measuring the size of the indentation to determine the hardness. The materials ability to resist surface deformations is directly associated with hardness [13]. Hence it is essential to undertake hardness test on the fabricated samples to evaluate the degree of wear and tear on the surface. The hardness value of additive manufactured udimet are shown in table 2.

Table 2: *Hardness test results*

Trial No.	Observed HV Value
1	74.57
2	72.22
3	71.47
4	73.53

5.2 Tribology Test

A form of tribological test called wear testing quantifies how much material is lost, damaged, or how the surface qualities change as a result of mechanical contact, sliding, rolling, or abrasion. The purpose of wear testing is to determine the durability and reliability of materials, coatings, and lubricants in diverse applications as well as to pinpoint the elements, such as load, speed, temperature, environment, and surface characteristics, that have an impact on wear resistance. Here we used the pin-on-disk test which is a commonly used tribological test to evaluate the wear and friction properties of materials in sliding contact. Under regulated load, speed, and lubrication conditions, a pin is moved against a revolving disc.

Wear testing may be used to improve the design and functionality of tribological systems by identifying the variables that impact wear resistance, such as load, speed, temperature, environment, and surface qualities. The tribology test results for additive manufactured udimet are shown in table 3.

Table 3: *Tribology test results*

Sl. No	Load (N)	Sliding velocity (m/sec)	Sliding Distance (m)	Wear rate (mm^3/s)
1	40	2	2000	143.845×10^{-3}
2	40	3	2500	440.885×10^{-3}
3	40	4	3000	6051.779×10^{-3}

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4	60	2	2500	224.421×10^{-3}
5	60	3	3000	315.06×10^{-3}
6	60	4	2000	6197.918×10^{-3}

6 Conclusions

The LPBF process is gaining popularity as it develops noticeably and incorporates modern technology in order to make it more efficient and competent. The LPBF approach is excellent for developing unique or customized products since it offers more design freedom, especially for the automotive, aerospace, and healthcare sectors. According to sustainability studies on the LPBF process, the two other main advantages are a large decrease in material waste and fuel use. A number of variables, including the characteristics of the powder, the laser's power, each layer's thickness, and the post-processing procedures, affect the quality and functionality of LPBF printed goods. Manufacturers may produce high-quality components with constant mechanical qualities by optimizing these factors.

LPBF does not, however, come without difficulties. The possibility of flaws, which include porosity, fractures, and distortions, that may adversely affect the component's strength and reliability, is one of the key restrictions. Careful process control and quality assurance procedures are needed to address these problems.

In conclusion, LPBF is an excellent technique for creating high-performance metal components with intricate geometries. To guarantee dependable and consistent output, quality control and process parameters must be carefully observed. As the technology develops, it has the ability to revolutionize the manufacturing sector and provide up new possibilities for applications like customization and light weighting.

7 Declarations

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References

[1] Charlotte Amelia Boig (2018), "The Application of Additive Manufacturing to Nickel-base Superalloys for Turbocharger Applications," White Rose eTheses.

[2] GauravPrashar and HiteshVasudev (2020), "Hot corrosion behavior of super alloys," Materials Today: Proceedings, volume 26, Page 1131-1135.

[3] Sachin Salunkhe, Sergio T. Amancio-Filho, J. Paulo Davim (2022), "Advances in Metal Additive Manufacturing" Advances in Metal Additive Manufacturing 1 st edition.

[4] Salom´e Sanchez, Peter Smith, Zhengkai Xu, Gabriele Gaspard, Christopher J. Hyde, Wessel W. Wits, Ian A. Ashcroft, Hao Chen, Adam T. Clare (2021), "Powder Bed Fusion of nickel-based superalloys," International Journal of Machine Tools and Manufacture, volume 165, Issue no: 103729.

[5] Gabriel Taillon and Kazuyoshi Miyagawa (2021), "Cavitation Erosion of Ni-Based Superalloys Manufactured by Forging and Additive Manufacturing," Journal of Failure Analysis and Prevention, volume 21, page 1902–1917.

[6] Kaufui V Wong and Aldo Hernandez (2012), "A Review of Additive Manufacturing," International Scholarly Research Notices, volume 2012.

[7] Gu DD, Meiners W, Wissenbach K, Poprawe R. Laser additive manufacturing of metallic components: materials, processes and mechanisms. Int Mater Rev 2012; 57:116–33.

[8] Kevin Minet , Ankit Saharan , Anja Loesser and Niko Raitanen (2019), "Superalloys, powders, process monitoring in additive manufacturing," Additive Manufacturing for the Aerospace Industry, chapter 8, page 163-185.

[9] Y.F. Shen, D. Gu and Y.F. Pan, "Balling Process in Selective Laser Sintering 316 Stainless Steel Powder," 315-*3162006 pp 357-360.*

[10] Spierings AB, Herres N, Levy G. Influence of the particle size distribution on surface quality and mechanical properties in AM steel parts. Rapid Prototyp J 2011; 17:195–202.

[11] Simonelli M, Tuck C, Aboulkhair NT, Maskery I, Ashcroft Ian, Wildman RD, Hague R. A study on the laser spatter and the oxidation reactions during selective laser melting of 316l stainless steel, AlSi10-Mg, and Ti-6Al-4v. In: The minerals, metals & materials society and asm international; 2015.

[12] Fayazfar H, Salarian M, Rogalsky A, Sarker D, Russo P, Paserin V, Toyserkani E. A critical review of powder-based additive manufacturing of ferrous alloys: process parameters, microstructure and mechanical properties. Mater Des 2018; 144:98– 128.

[13] Nikhil Khatavkar, Sucheta Swetlana, Abhishek Kumar Singh (2020), "Accelerated prediction of Vickers hardness of Co- and Ni-based superalloys from microstructure and composition using advanced image processing techniques and machine learning," Acta Materialia, volume 196, page 295-303.