Madanapalle Institute of Technology and Science
Department of Mechanical Engineering

Project work: Phase II

CNC DRILLING OF SELECTIVE LASER MELTED Ti-6Al-4V ALLOY

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PROJECT GUIDE :

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Problem Statement

Selective Laser Melting (SLM) of Ti-6Al-4V alloy has proven to be a promising technique for fabricating complex structures with high dimensional accuracy and material properties. However, the machining of these parts, particularly CNC drilling, remains a challenge due to the material's high strength, low thermal conductivity, and poor machinability. The lack of a reliable and efficient drilling process for SLM Ti-6Al-4V alloy limits its applications in various industries such as aerospace, biomedical, and automotive. Therefore, the objective of this study is to develop an optimized CNC drilling process for SLM Ti-6Al-4V alloy that achieves high accuracy, productivity, and tool life while minimizing the machining-induced damage and costs.

Introduction

Ti-6Al-4V:

Ti-6Al-4V is a widely used titanium alloy known for its exceptional strength, low density, and excellent corrosion resistance. This alloy exhibits a favorable combination of mechanical properties, making it highly desirable for numerous applications across various industries. One of the notable characteristics of Ti-6Al-4V is its high strength-to-weight ratio, which surpasses that of many other engineering materials, including steel and aluminum alloys. This property makes it particularly advantageous in weight-sensitive applications where strength is critical, such as aerospace components, aircraft structures, and gas turbines.

- **Titanium (Ti):** It forms the majority of the alloy, accounting for approximately 90% of the composition. Titanium is a lightweight metal with excellent strength-to-weight ratio, high melting point, and corrosion resistance.
- **Aluminum (Al):** Aluminum makes up around 6% of the alloy composition. It is added to enhance the alloy's strength and improve its hardenability. Aluminum also contributes to the overall corrosion resistance of the alloy.
- **Vanadium (V):** Vanadium constitutes about 4% of the alloy composition. It plays a crucial role in increasing the strength and heat resistance of Ti-6Al-4V. Vanadium forms a hard, stable precipitate during heat treatment, which further improves the alloy's mechanical properties.

Introduction

Applications :

- Aerospace industry: Used for aircraft structural components, landing gear, engine parts, and airframe components, benefiting from its high strength-to-weight ratio and corrosion resistance.
- Medical and dental implants: Biocompatible and corrosion-resistant, making it suitable for hip and knee replacements, bone plates, dental implants, and surgical instruments.
- Marine and offshore industry: Utilized in ship hulls, propellers, offshore platforms, and underwater equipment due to its corrosion resistance in seawater.
- Sports equipment: Used in bicycle frames, golf club heads, tennis racquets, and other sports components due to its high strength and lightweight nature.
- Automotive industry: Employed in suspension components, exhaust systems, engine valves, and other parts to reduce weight and enhance performance.
- Consumer goods: Utilized in luxury items such as watches, jewelry, eyewear frames, and writing instruments due to its strength, durability, and aesthetic appeal.

Introduction

Mechanical properties of Ti-6Al-4V:

Mechanical Properties		
Hardness, Brinell	318	
Hardness, Knoop	346	
Hardness, Rockwell C	34	
Hardness, Vickers	333	
Tensile Strength, Ultimate	1010 MPa	
Melting Point	Max 1700 °C	Max 3090 °F

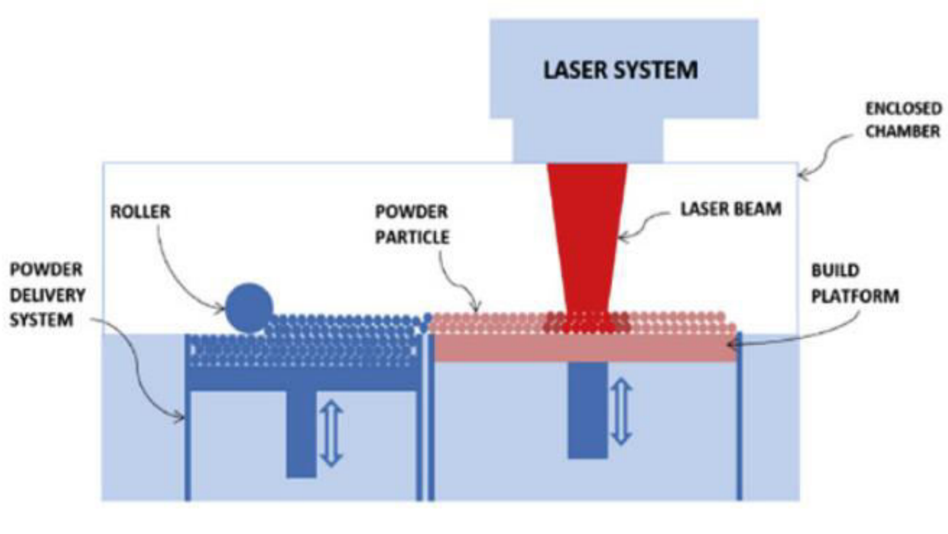
Introduction

Selective laser melting (SLM):

Selective laser melting (SLM) is a type of 3D printing technology that uses a high-powered laser to selectively melt and fuse together layers of powdered material to create a solid object. SLM involves the use of a CAD (computer-aided design) model to create a 3D object, which is then sliced into thin layers.

WHY SLM ?

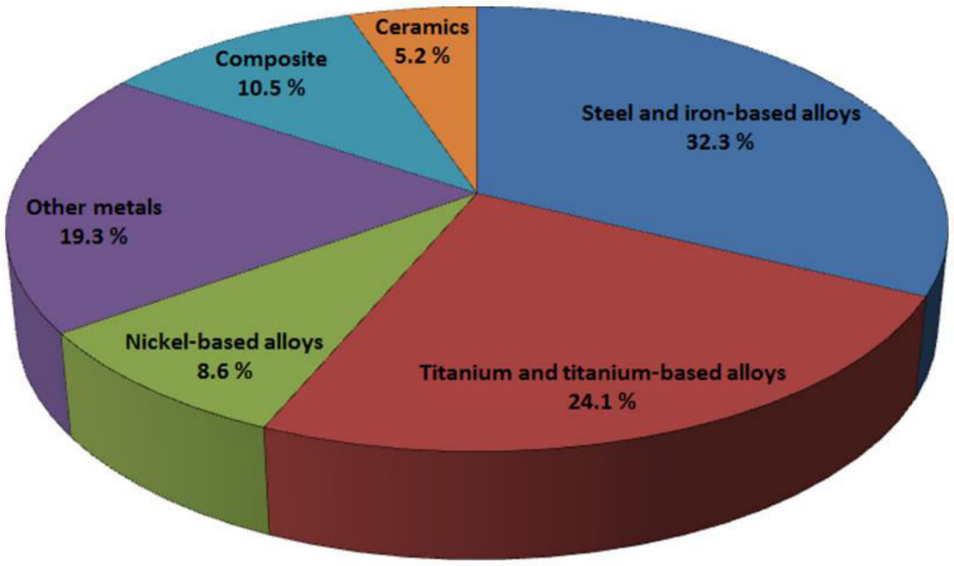
Selective Laser Melting (SLM) is the preferred 3D printing technology for producing high-quality metallic parts due to its high precision, accuracy, excellent mechanical properties, and material versatility. Compared to other 3D printing methods, SLM produces less waste and is more sustainable and cost-effective. Its ability to produce complex geometries and tight tolerances makes it ideal for industries such as aerospace, biomedical, and automotive.



Literature Review

C. Y. Yap et. all : Review of selective laser melting: Materials and applications , 2015

- This literature survey has shown that research in SLM has been mostly focused on metallic materials, with steel and titanium accounting for over half of all the publications from 1999 to 2014.
- The popularity of steel and titanium based materials is due to their applications in high value added industries, such as aerospace and medicine.
- In SLM, support structures are required for overhanging parts. These support structures function as anchors and heat sink to conduct excessive heat away.



Literature Review

C. Y. Yap et. all : Review of selective laser melting: Materials and applications , 2015

- Hussein et al. examined the design of support structures with Ti6Al4V so as to reduce the required volume fraction for overhanging features during SLM process
- This would significantly reduce the amount of materials needed as support structure, reduce the time required for support removal, and laser scanning time required for support structure.
- It would also lower the cost of the SLM process as more powders can be reused for subsequent batches of production.

Literature Review

Sebastian Bremen et .all :Selective Laser Melting,2012

- The examinations shown in this paper illustrate that the manufacturing method SLM offers a great potential to solve the challenges of serving individual customer requirements, on the one hand, and high quality as well as low cost products, on the other.
- However, the current state of the SLM process is not yet suited for series production because of the lacking cost efficiency and productivity.
- In order to improve this situation, Fraunhofer Institute for Laser Technology ILT has redesigned and rebuilt an SLM machine equipped with a 1 kW laser source and a multi-beam optical design.
- Thereby, the process-related build-up rate, which is a benchmark for the productivity of the SLM process, can be increased.

Literature Review

Haiyang fan et.all :Effects on Ti–6Al–4V (Ti-64) titanium alloy fabricated by selective laser melting (SLM),2020

- In this study, SLM was successfully applied to Ti-64 alloy for the first time, achieving a crack-free microstructure of 99.5% density.
- Subsequently, standard aging was conducted to understand the thermal stability of the as-built microstructure and the effects on mechanical properties.
- Instead of the conventional bimodal or lamellar structure, the SLM-processed Ti-64 exhibited a microstructure, with a weak texture at a polycrystalline level due to the diverse selection of variants.

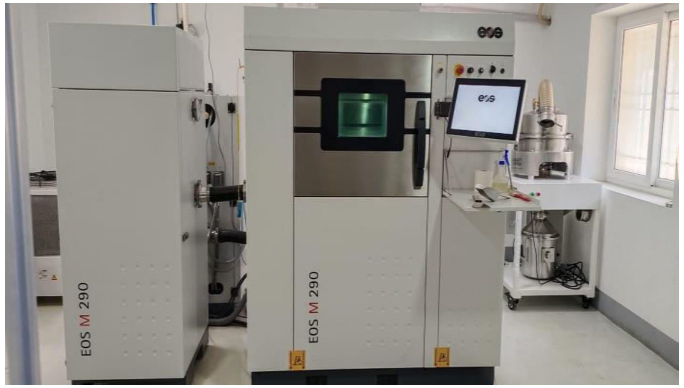
Literature Review

Haiyang fan et.all :Effects on Ti–6Al–4V titanium alloy fabricated by selective laser melting (SLM),2020

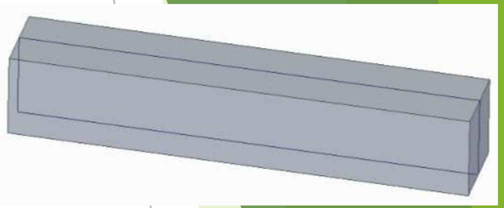
- The 5% ductility of SLM Ti-6$ was mainly owed to the unique structure formed thanks to the complex thermal cycles of SLM.
- The as-built sample was further reinforced by direct aging, leading to the historically high strength of 1510 MPa but at the cost of ductility reduction.
- In this study, it was proposed a strengthening mechanism by β nano precipitates originated from the martensite decomposition at low temperatures.

Methodology

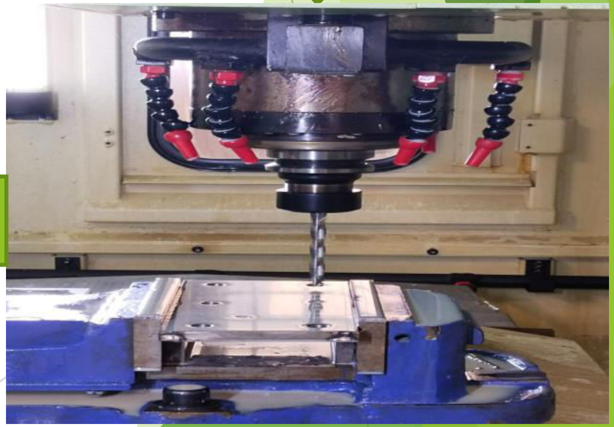
Ti-6Al-4V
ALLOY



SLM 3D METAL PRINTING



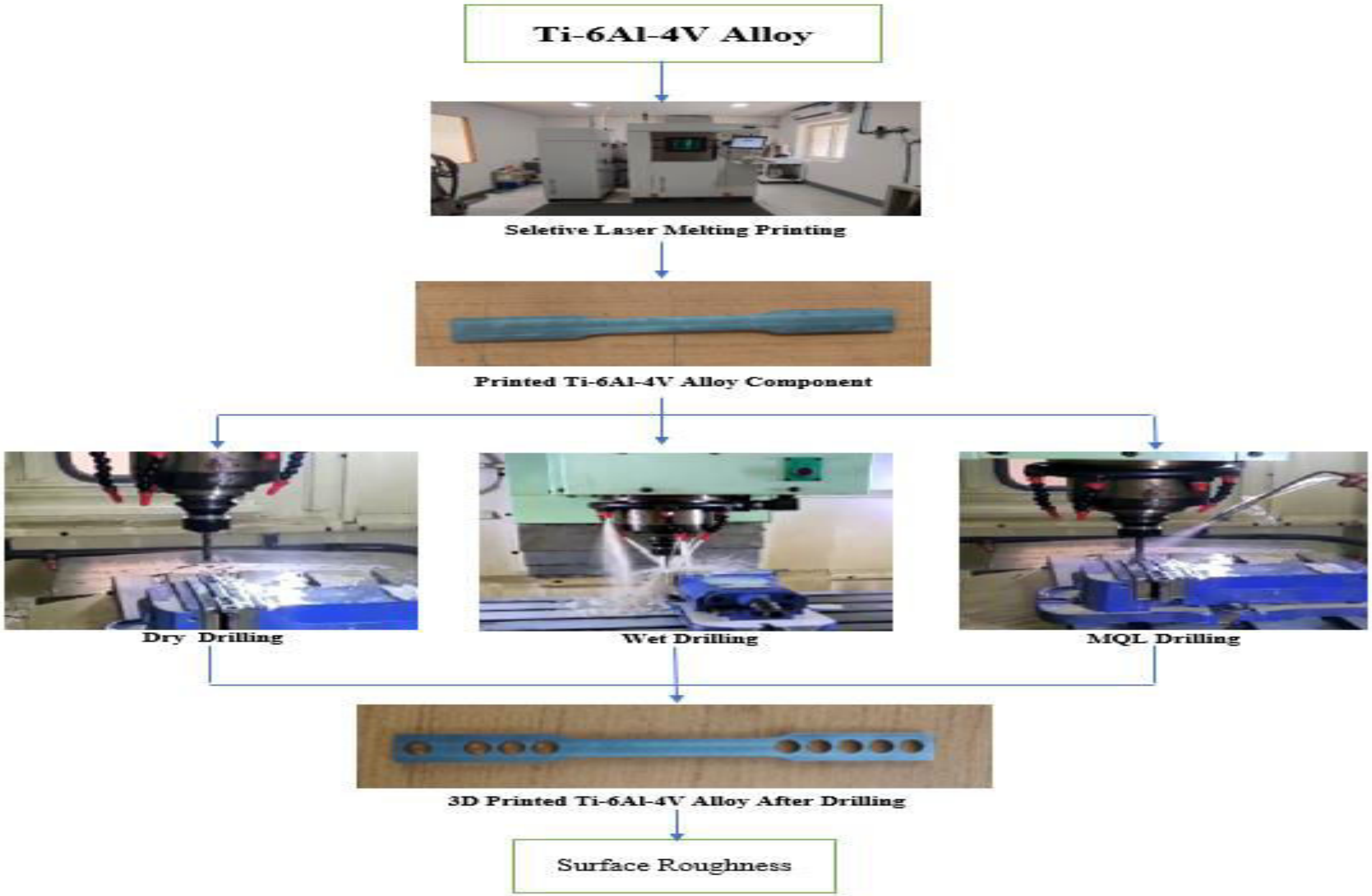
3D PRINTED OBJECT



CNC DRILLING

SURFACE ROUGHNESS

Methodology



Methodology

SLM 3D Printing

Methodology

- Table 1: Drilling Parameters

Drilling Types	Cutting Speed (RPM)	Feed Rate (mm/rev)
WET	800	0.03
	1000	0.06
	1200	0.09
DRY	800	0.03
	1000	0.06
	1200	0.09
MQL	800	0.03
	1000	0.06
	1200	0.09

Methodology

Surface Roughness Test :

Methodology

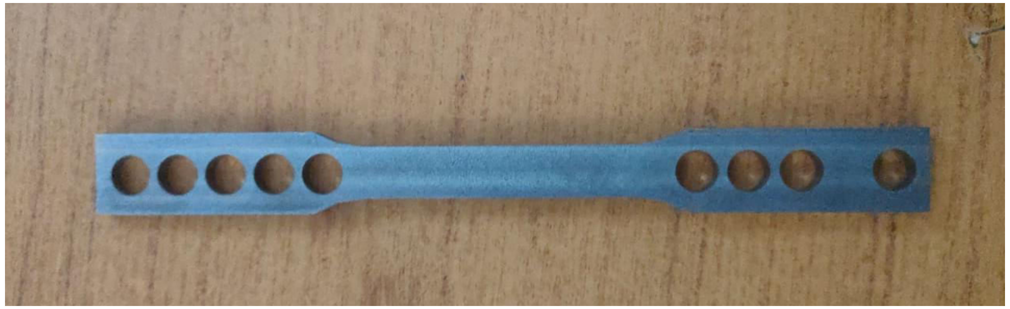
CNC Program for Drilling Operation:

```
G00G55G40G90G94
T12D1
M6
G0Z100
G0X08Y0
Z5
MCALL CYCLE83(25,0,2,-10,,-1,,100,0,0,50,1,0,4,2,0,2,0,1,1122112)
G95 X+8 Y0 S800 F0.03
M01
G91 X+12 Y0 S1000 F0.06
M01
G91 X+12 Y0 S1200 F0.09
M01
G91 X+12 Y0 S800 F0.03
M01
G91 X+98 Y0 S1000 F0.06
M01
G91 X+12 Y0 S1200 F0.09
M01
G91 X+12 Y0 S800 F0.03
M01
G91 X+12 Y0 S1000 F0.06
M01
G91 X+12 Y0 S1200 F0.09
M01
M30
```

Result

Before Drilling Operation

After Drilling Operation



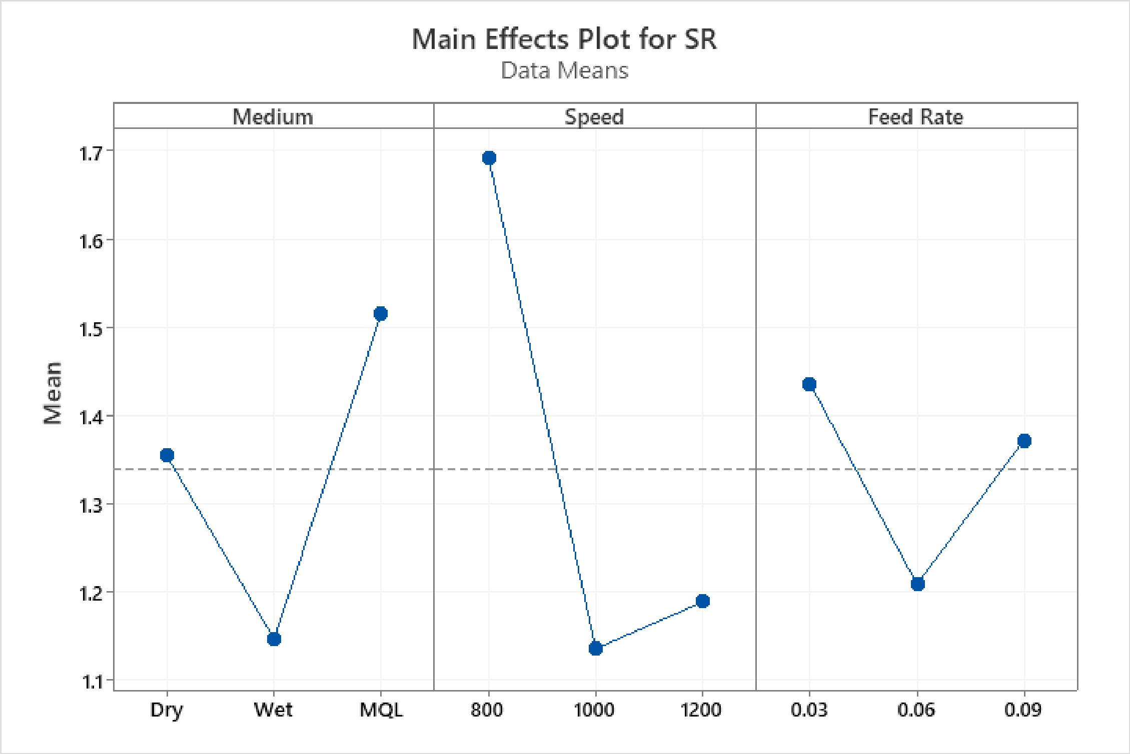
Result

Surface Roughness For Wet , Dry and MQL Machining

Drilling Types	Cutting Speed (RPM)	Feed Rate (mm/rev)	Ra (µm)	Rz (µm)	Rq (µm)
WET	800	0.03	0.0608	4.15	1.09
	1000	0.06	1.0103	6.670	1.631
	1200	0.09	1.2342	7.647	2.11
DRY	800	0.03	2.0410	11.728	2.813
	1000	0.06	1.2355	9.201	2.326
	1200	0.09	1.2682	8.841	2.013
MQL	800	0.03	1.072	5.959	1.423
	1000	0.06	1.458	9.067	2.123
	1200	0.09	2.148	11.372	2.719

Result

Main Effects Plot for SR



Conclusion

Conclusion

In conclusion, current research on CNC drilling of selective laser melted (SLM) Ti-6Al-4V alloy has shown that it is a potential method for creating high-quality drilled holes in this material. SLM Ti-6Al-4V alloy is a difficult material to process because of its distinctive microstructure and characteristics, but CNC drilling has shown to be a successful technique for producing accurate holes with high surface polish and little tool wear. But there is still a lot of need for more investigation in this field.

Future research should focus on improving the process parameters, examining how drilling parameters affect microstructure and characteristics, and examining the surface integrity of drilled holes, among other relevant topics.

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Thank You!!!