ME547 - TERM PROJECT

Machining Analysis of Additively Manufactured Metallic Components with Varied Density

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OBJECTIVES

1	UNDERSTANDING DENSITY VARIATION THROUGH SLM
2	ANALYZE CUTTING FORCES USING A DYNAMOMETER
3	IDENTIFICATION OF TYPE / NATURE OF LOADING ON TOOL
4	TOOL WEAR ANALYSIS OF TOOL TIP

1.INTRODUCTION

- Motivation for the project lies in the fact that we require Light weight components in various sectors like Aerospace , Biomedical and Space Applications which are not compromising on Strength and safety .
- Complexity and freedom of design leads us to Additive manufacturing.
- We need to machine such components to get dimensional accuracy.
- So , this projects focuses on fabrication and machining analysis of varied density metallic components .

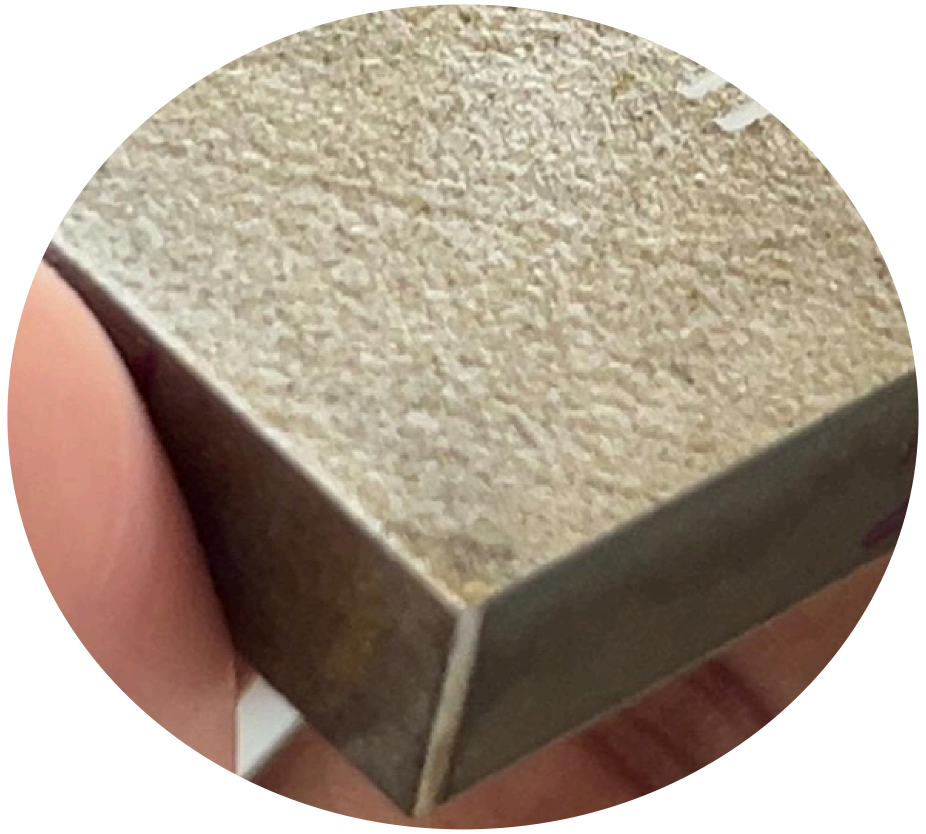
2. Fabrication of Samples

1. Material Used : Stainless Steel 316L (8 gm/cm^3)
2. Technology Used : Selective Laser Melting (SLM)
3. Machine Used : EOS M 290 metal 3D printer
4. Density Varied : Modifying **Volumetric Energy Density** (varying hatch spacing only)
5. Size of components = 50*100*10 mm^3

2.1 Visual Tour of Manufacturing

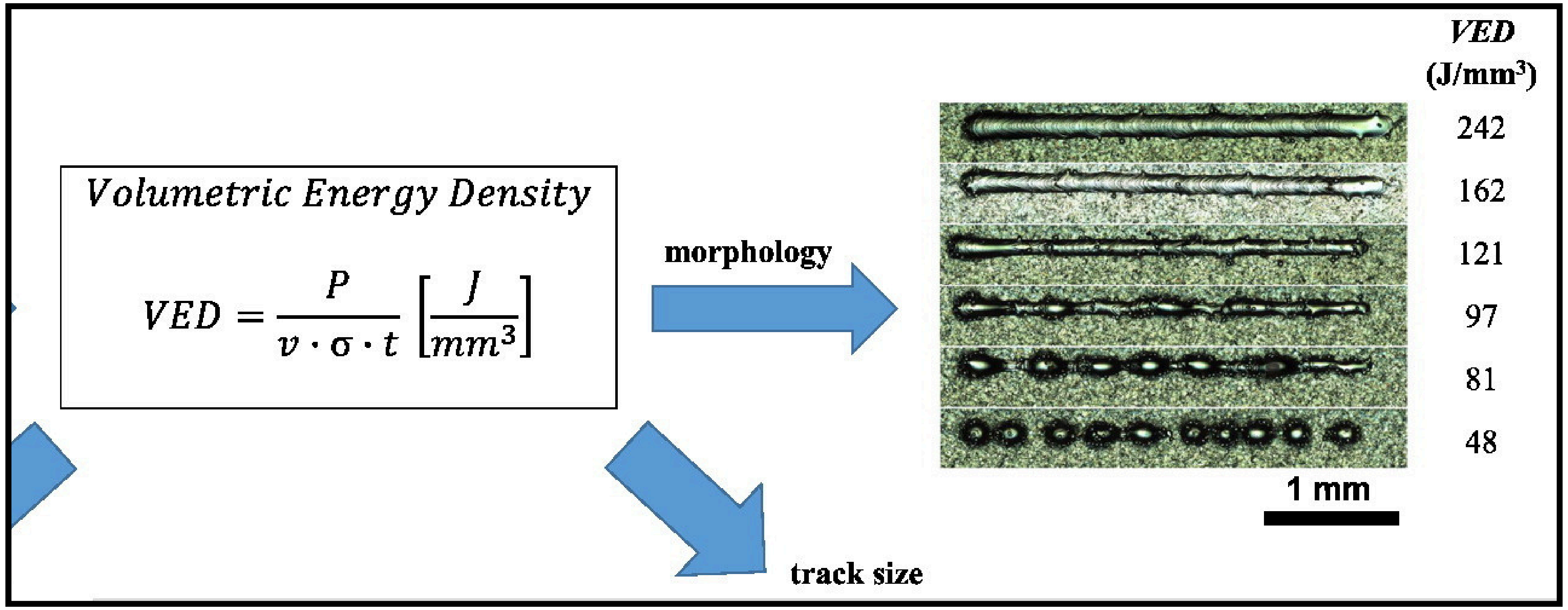
SS316L Powder

SLM : EOS M 290 metal 3D printer



Components with varied density

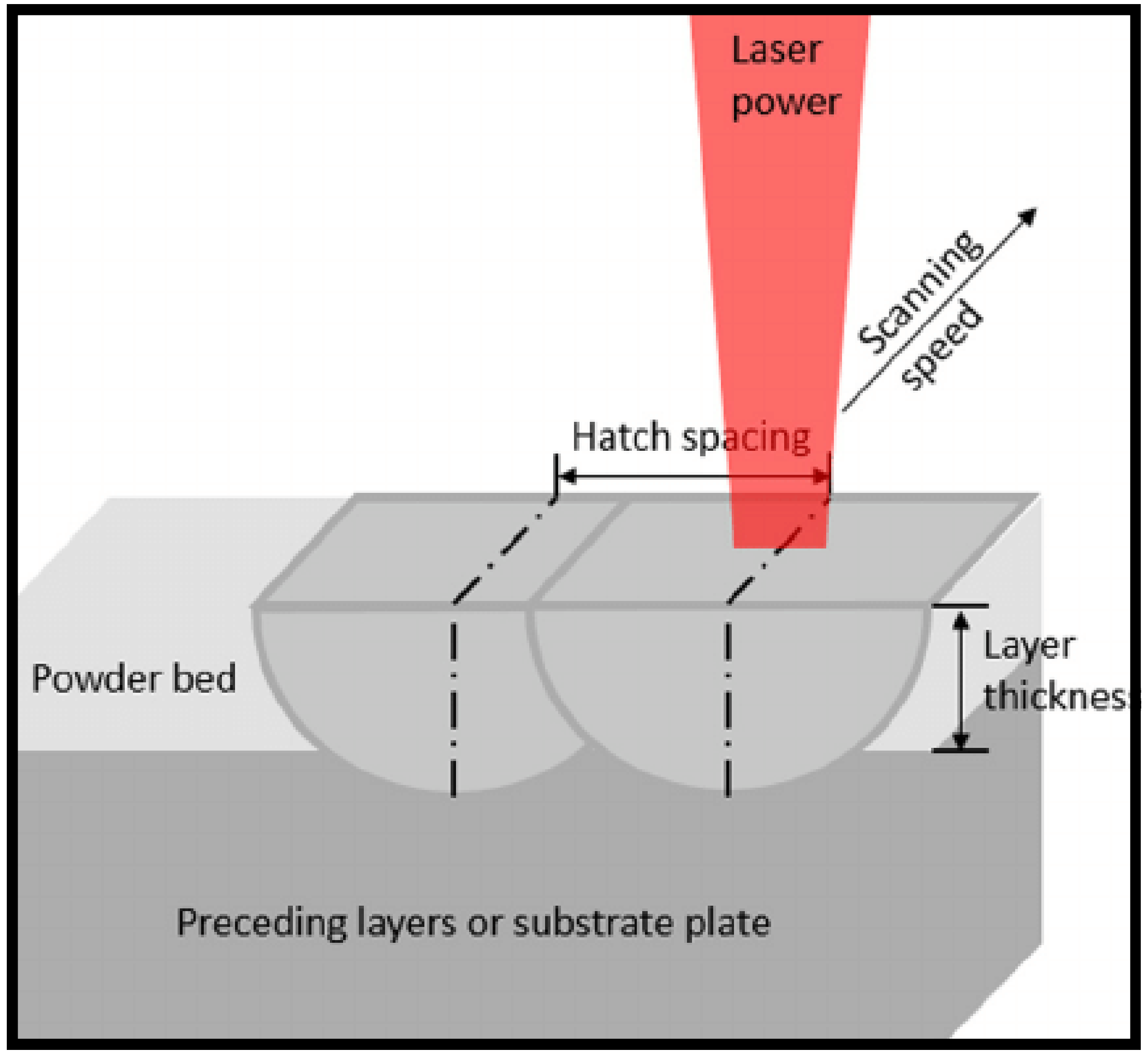
2.2 Density Variation



Source :https://doi.org/10.1016/j.matdes.2016.10.037

1. **Volumetric Energy density is a value which determines the quality of layer formation in SLM process.**
2. **There is a window for each material in which the best layer formation will take place.**
3. **It depends upon 4 parameters : LASER POWER , SCANNING SPEED , LAYER THICKNESS and HATCH SPACING .**

2.2 Hatch Spacing Variation



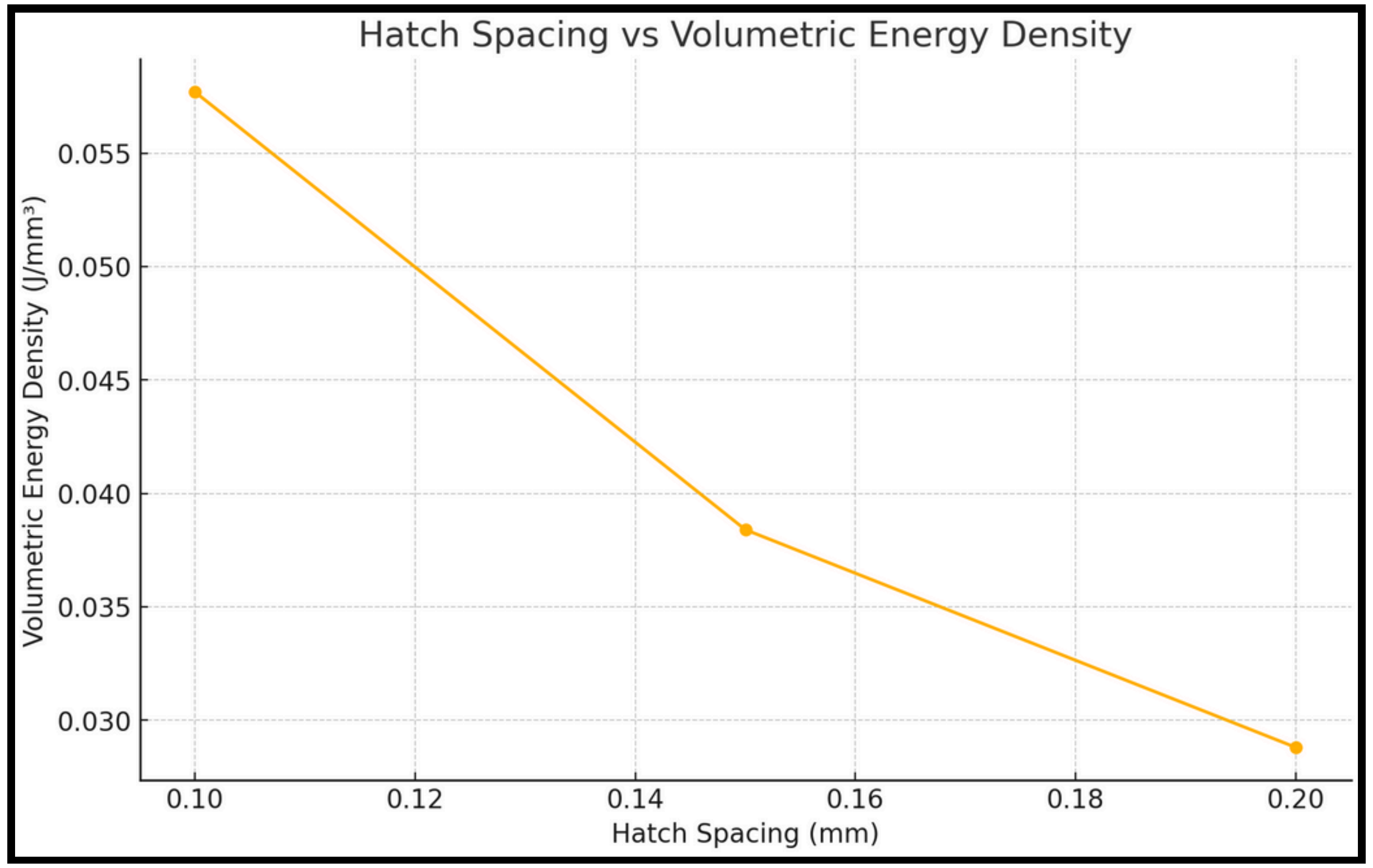
Source :https://link.springer.com/article/10.1007/s40964-022-00328-0

1. Hatch spacing = Distance between adjacent laser scan tracks
2. Lower hatch spacing → Better melt pool overlap → High density
3. Higher hatch spacing → Porosity → Reduced density

Keeping all other parameters constant in this experiment , we are only varing the Hatch spacing.

2.3 SLM PARAMETRS

S.No.	Laser Power (W)	Scan Speed (mm/s)	Hatch Spacing (mm)	Layer Thicknes s (mm)	Volumetric Energy Density (J/mm³)
1	214	928	0.1	40	0.0577
2	214	928	0.15	40	0.0384
3	214	928	0.2	40	0.0288



2.4 Density and Hardness Measurements

S.No.	Mass (gm)	Volume (cc)	Density (gm/cc)	In-filled Density (%)
1	392	50.577	7.751	97
2	376	49.974	7.524	94
3	381	53	7.189	90

S.No.	Hardness (HRC)
1	77.2
2	72.15
3	60.35

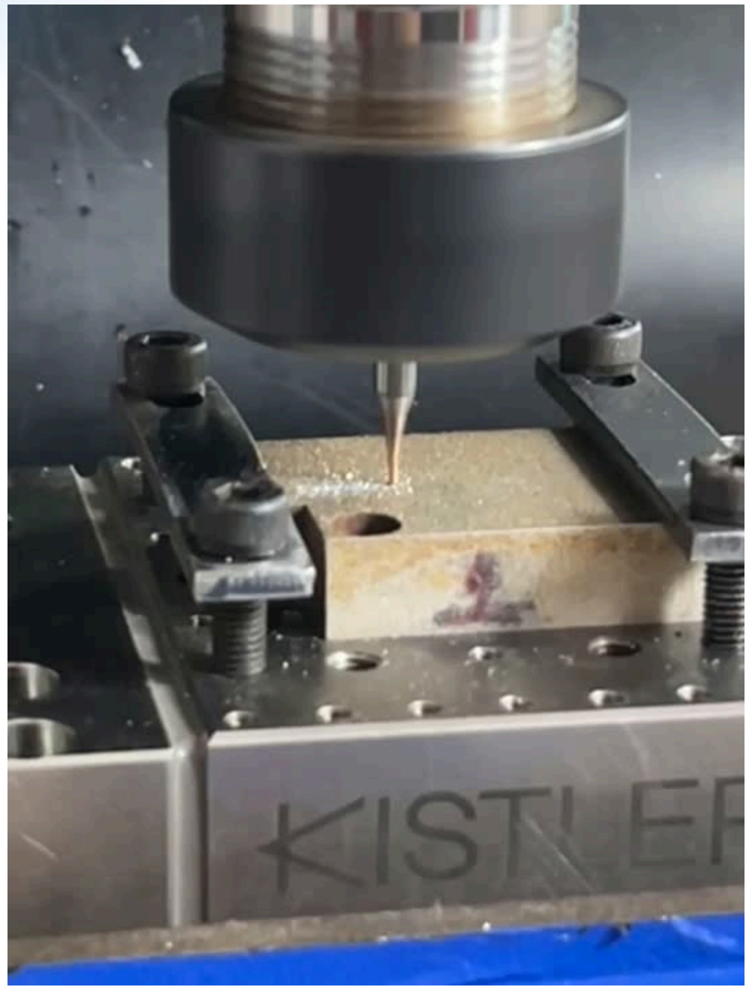
1. **We obtained 3 SAMPLES ; Measured their MASS and VOLUME.**
2. **Volume Variation is due to height variation as wire EDM Cutting is tapered.**
3. **A significant change in Density is observed .**

1. **Measured Rockwell Hardness .**
2. **Diamond indenter used**
3. **Least dense Sample 3 has least HRC**
4. **Thus porosity , makes the material softer.**

3. MACHINING OPERATION

1. Machining Operation: End Milling
2. Machine Tool Used : VMC (Lab 412)
3. Tool Material : Tungsten Carbide 0.9mm End mill
4. Same cutting parameters for all 3 samples
5. RPM: 2500 | Feed: 10 mm/min | DOC: 0.15 mm
6. Kistler Dynanometer used for Force data
7. Wire EDM used to adjust size to 50*30*10 to fit dynamometer

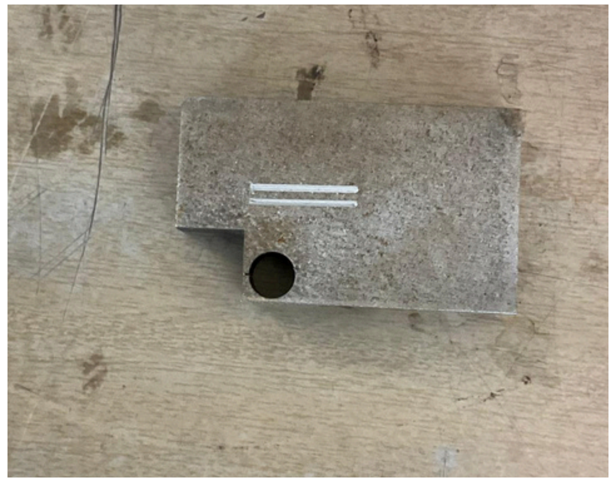
3.1 Experimental Setup



Kistler Charge Amplifier Type 5070A

TOOL

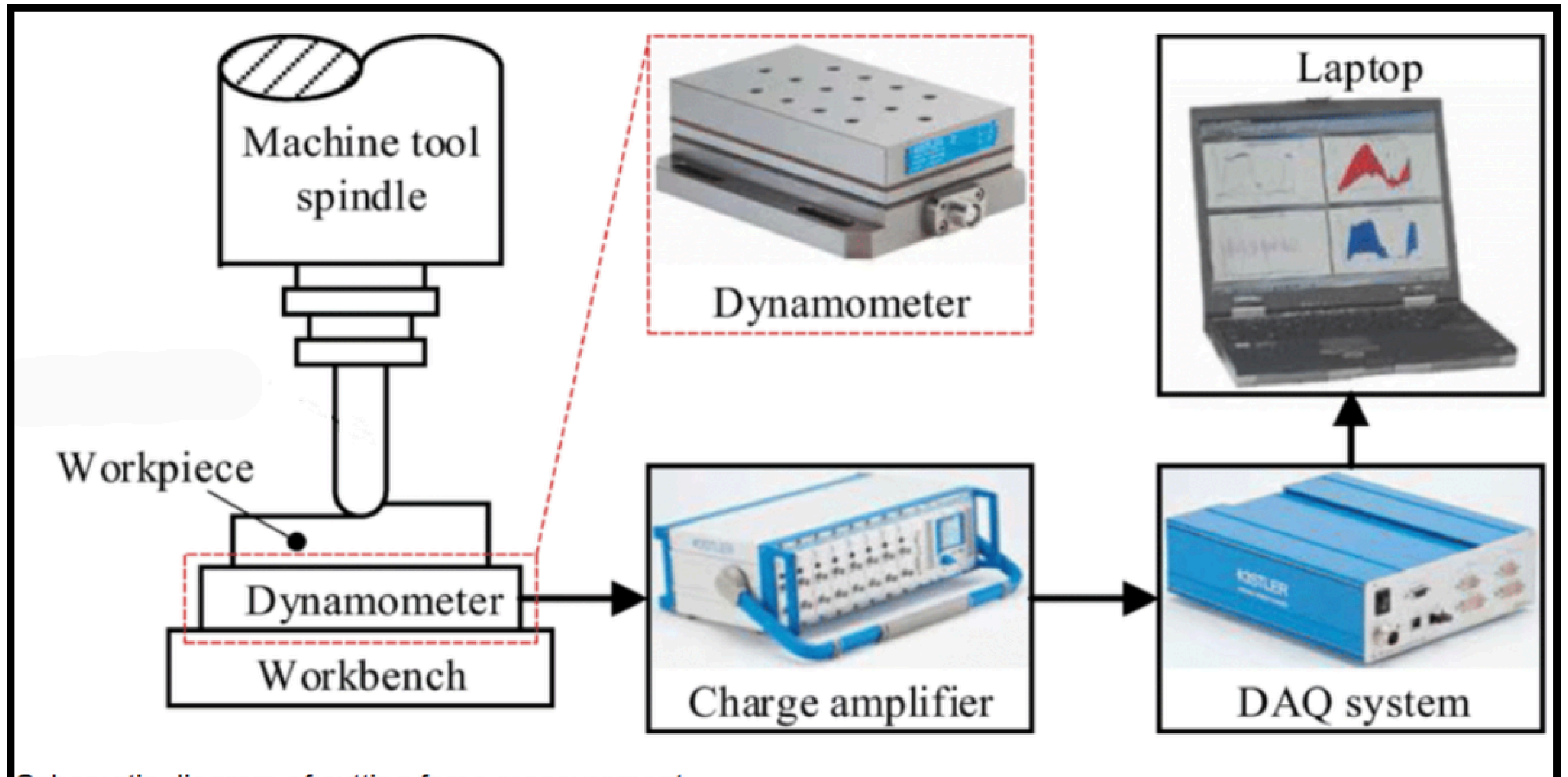
TOOL COLLET



WORKPIECE

3.2 Working of Dynamometer

1. Uses piezoelectric quartz sensors to precisely measure machining forces.
2. Quartz produce elctrical signals when squezzed or strecthed.
3. Amplifier make the signals detectable by amplification
4. Transducer converts signals to electrical voltage
5. We get Multi directional forces in excel sheet as well as graph in PC



Schematic diagram of cutting force measurement

Source https://www.kistler.com/INT/en/cutting-force-measurements-with-dynamometers/C00000017

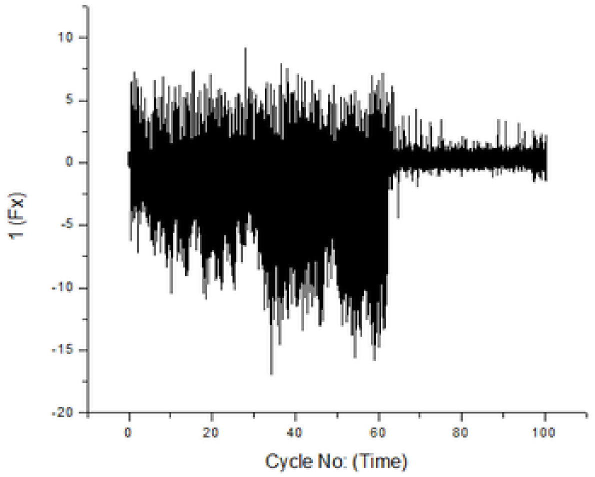
3.3 MRR CALCULATION

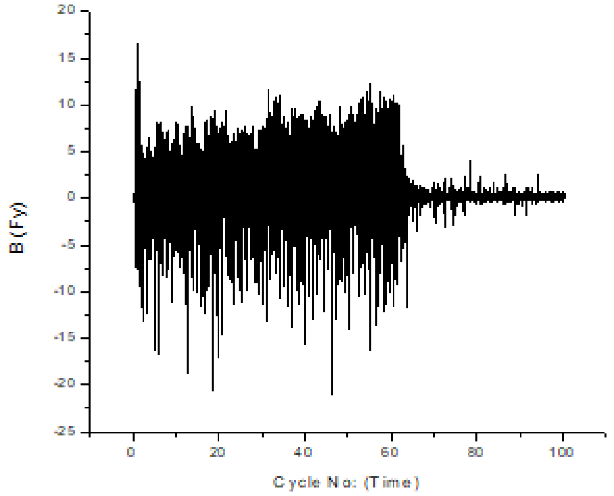
Sample No.	Density (gm/cc)	Initial Weight (gm)	Final Weight (gm)	Mass Loss (gm)	Time (s)	MRR (cc/s)
1	7.751	104.1783	104.1654	0.0129	60	2.77×10^{-5}
2	7.524	101.9113	101.8957	0.0156	60	3.46×10^{-5}
3	7.189	99.7442	99.7254	0.0188	60	4.36×10^{-5}

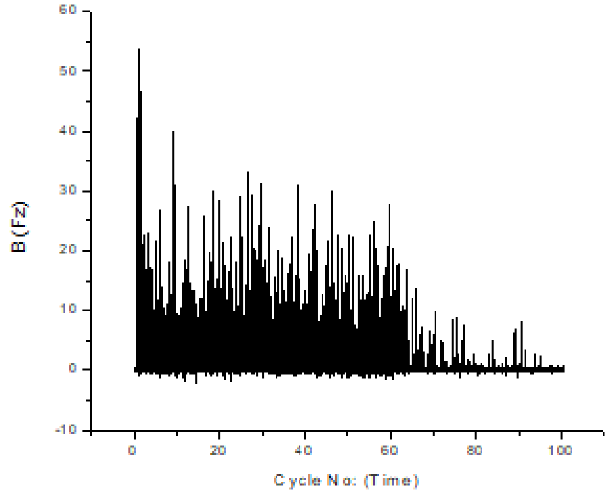
- Quite Interesting!! We think lower-density samples experience more material removal due to reduced structural integrity during machining.
- We need GOOD MRR in low density but we need to look into Tool conditions also.

4. FORCE ANALYSIS

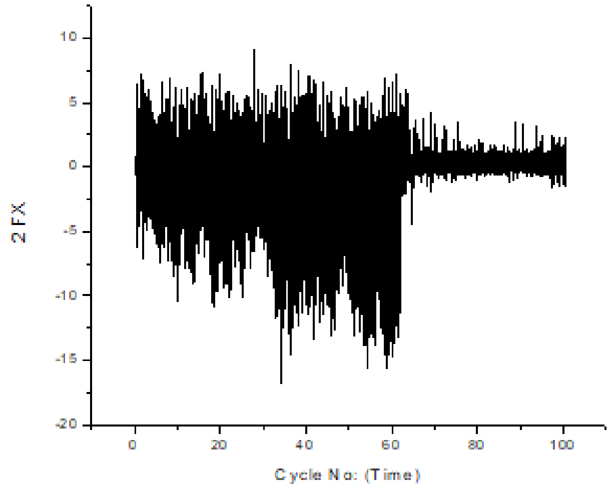
Sample 1

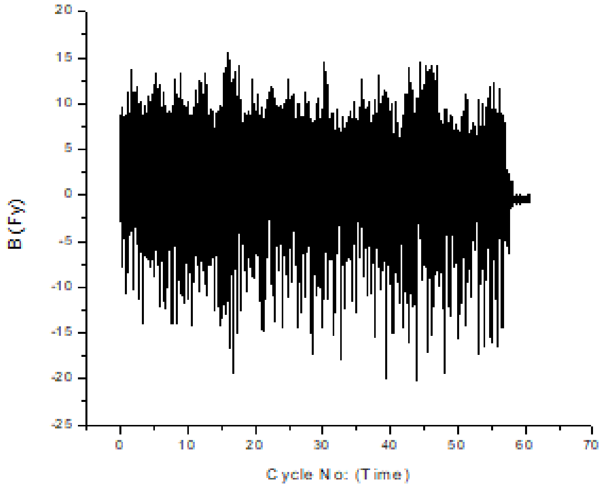


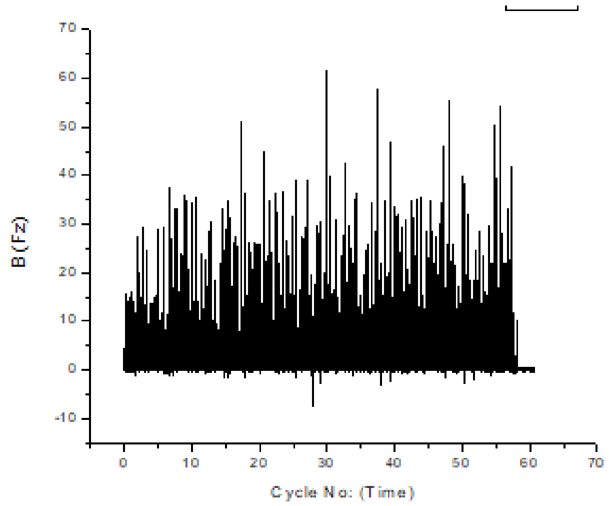




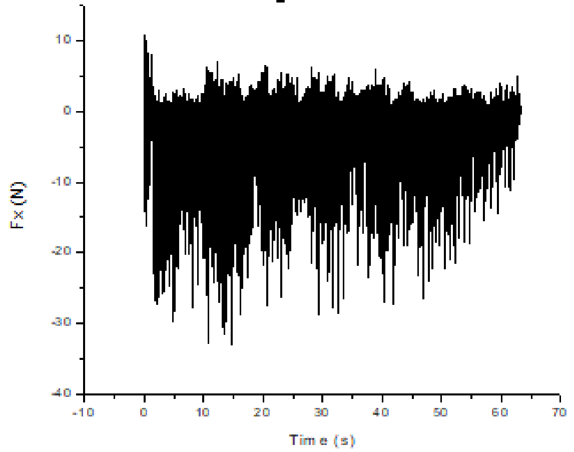
Sample 2

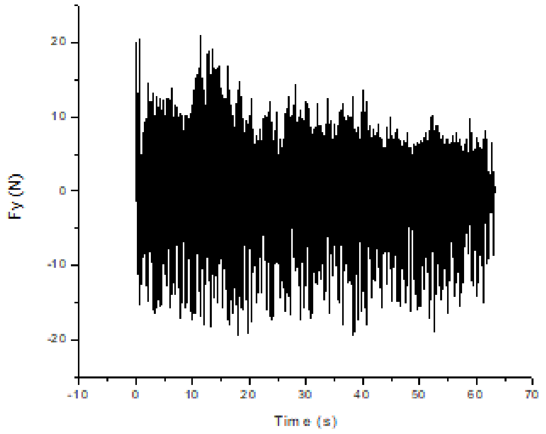


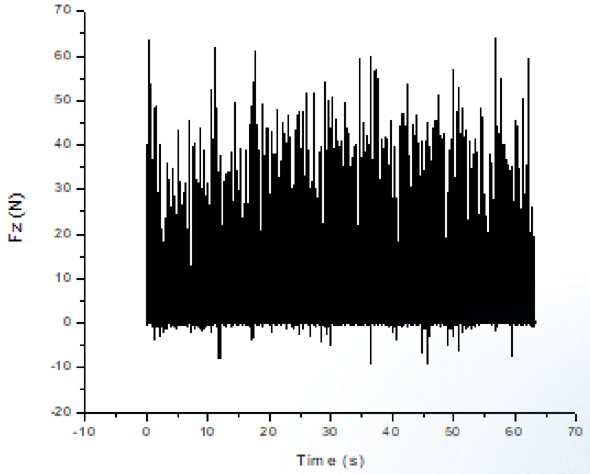




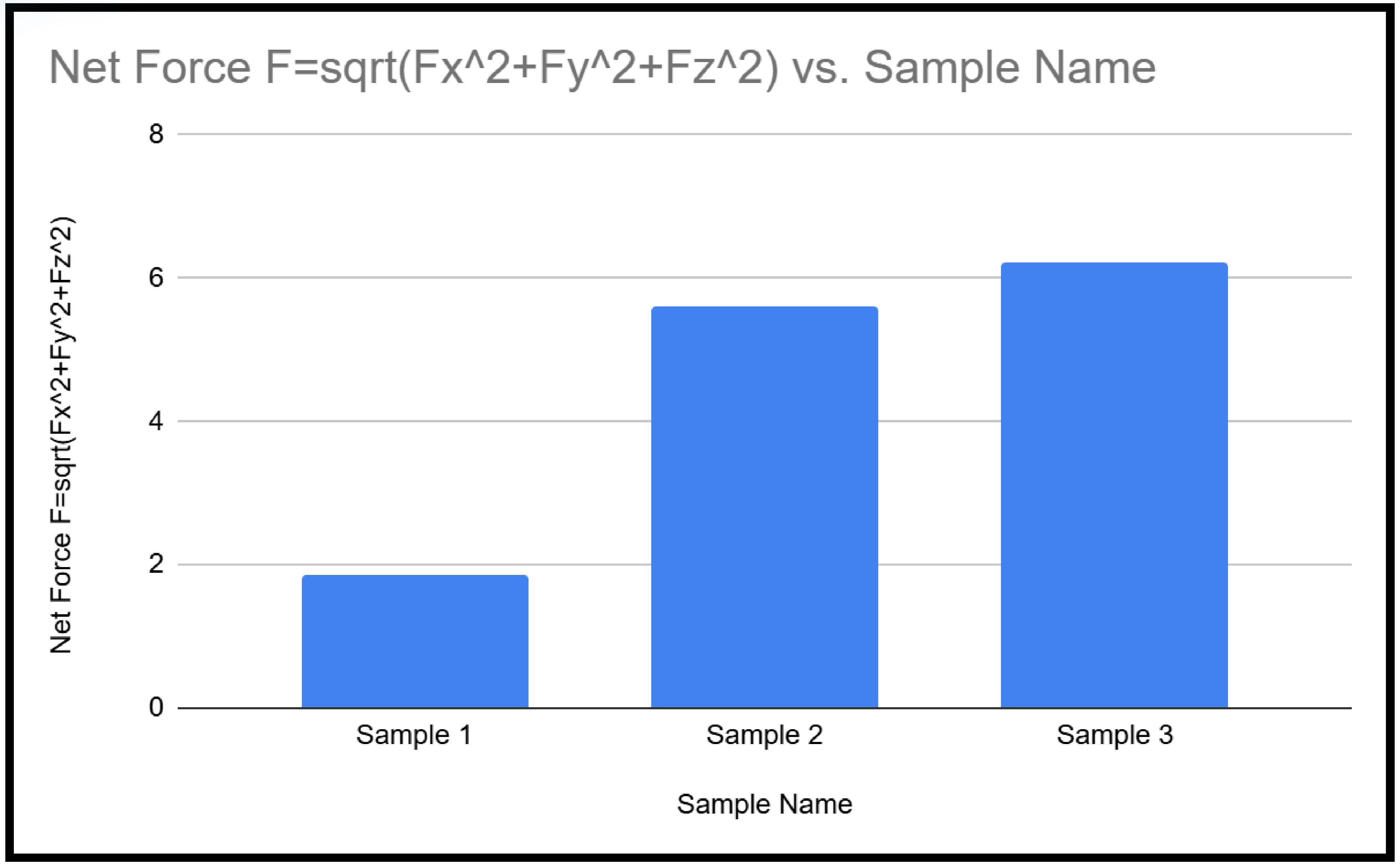
Sample 3







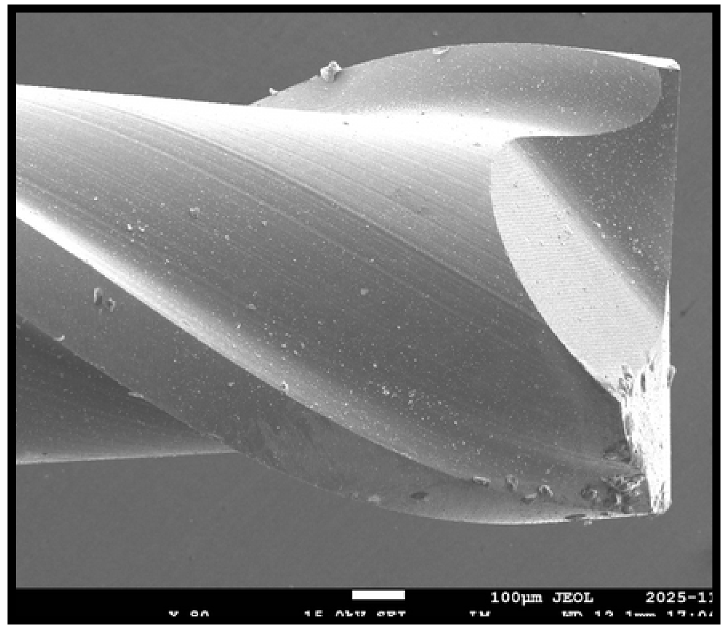
4.2 NET FORCE ANALYSIS



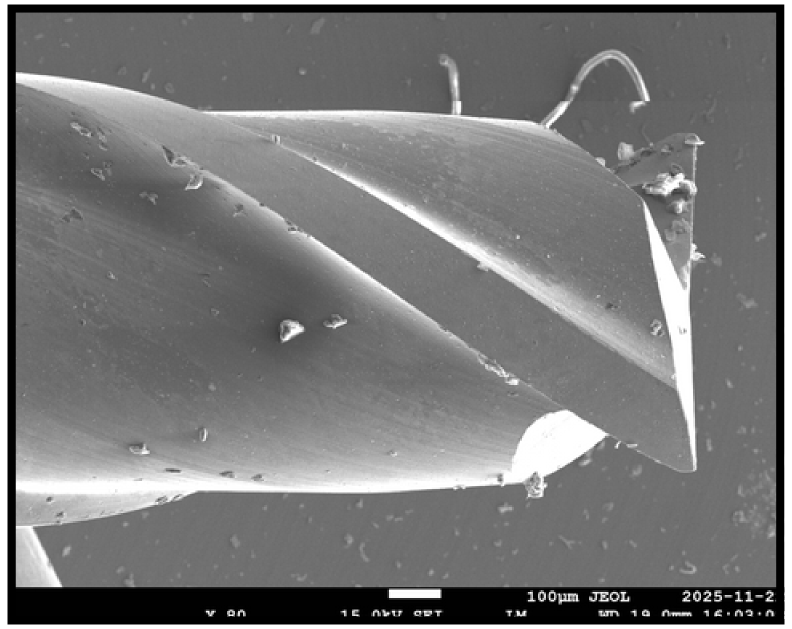
Sample Name	Net Force F=sqrt(Fx^2+Fy^2+Fz^2)
Sample 1	1.85
Sample 2	5.60
Sample 3	6.21

This shows that Net Force is more for less density sample i.e.tool experiences more impact load due to interupted cuttting caused by pores.

5. Tool Wear

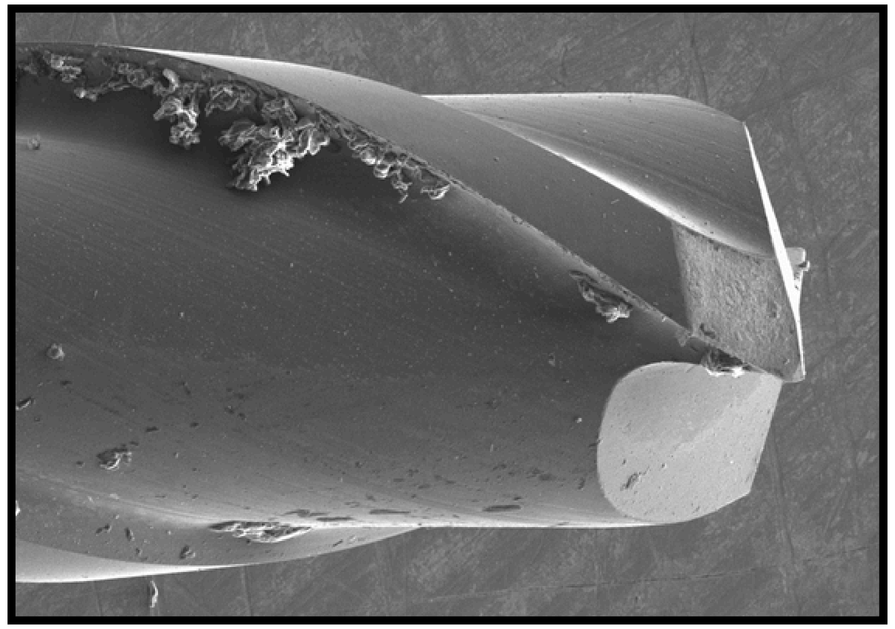


- Ideal Tool before machining
- Cutting edges and 2 flutes are visible
- Rake surface and flank can be identified
- refrence



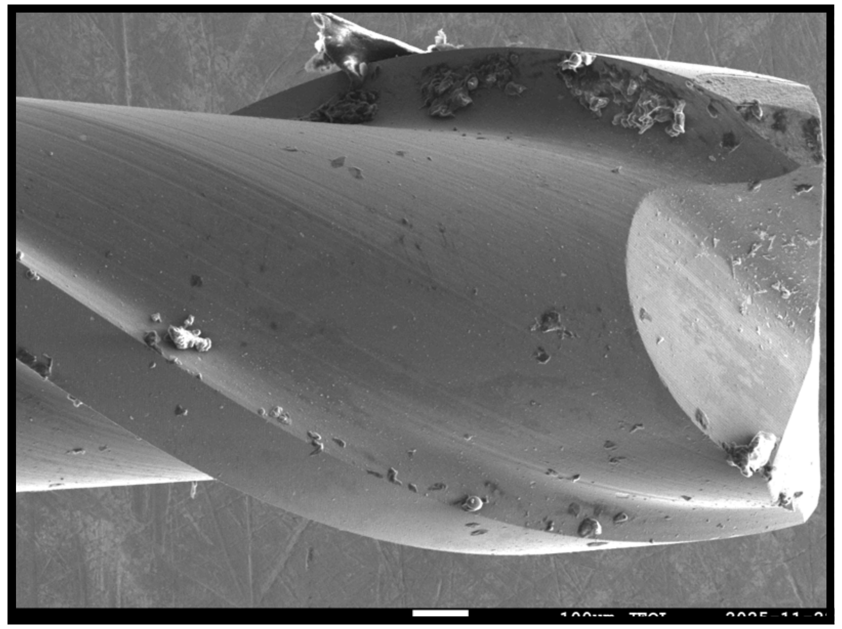
Sample 1 (97% density):

- Very minimal wear Clean cutting-edge geometry maintained
- Negligible flank and crater wear
- Slight adhesive spots only



Sample 2 (94% density):

- Noticeable adhesion on rake surface (Built-Up Edge)
- It will lead to crater wear when tool is further used
- Slight Abrasive scratches visible



Sample 3 (90% density):

- Significant adhesive wear due to increased porosity
- Higher vibration-induced abrasive wear

As density decreases, porosity increases → loading become Fluctuating natured → resulting in higher wear rates on the tool.

6. RESULTS AND CONCLUSIONS

1. Machinability strongly depends on infilled density
2. Hardness decreases with decreased density
3. MRR should be good i.e. achieved in lesser density
4. But Force and Tool wear must be minimal
5. Optimum density reduces forces, vibrations, and tool wear
6. SLM parameters significantly influence performance
7. So, we conclude that we can merge additive and substractive manufacturing to get optimised parts!!

REFERENCES

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THANK YOU !!