Investigation on Laser Based Positive texturing of Single Point Cutting Tool Using Additive Manufacturing Route

M.Tech Thesis

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Investigation on Laser Based Positive texturing of Single Point Cutting Tool Using Additive Manufacturing Route

A THESIS

Submitted in partial fulfillment of the

requirements for the award of the degree

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in

Mechanical Engineering

With specialization in

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by

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Indian Institute of Technology Indore

Candidate's Declaration

I hereby certify that the work which is being presented in the thesis entitled" **Investigation on laser based positive texturing of single point cutting tool using additive manufacturing route**" in the partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Mechanical Engineering** with specialization in **Production and Industrial Engineering** submitted in the **Discipline of Mechanical engineering, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from May 2018 to June 2019 under the supervision of **Dr. I.A. Palani** of Discipline of mechanical engineering. The matter presented in this thesis has not been submitted by me for the award of any degree from any other institute.

Shivam Mishra

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(Dr. I.A. Palani)

Shivam Mishra has successfully completed his M.Tech Oral Examination held on ……

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Signature of PSPC member 1: **Signature of PSPC member 2:**

Date: **Date:**

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Shivam Mishra

Dedicated

to

My family

Abstract

Researches in dry machining have shown that surface texturing has the potential to enhance tribological conditions. Researchers have studied the effects of surface texturing on cutting tool rack surfaces to enhance the machining performance by inducing change in the tribological conditions at the interface of tool and chip. An investigation on the effects of positive texturing on high-speed steel cutting tool for machining of mild steel rod was performed. Positive textures were introduced using continuous laser power & Nickel powder. Dry machining operation is performed on mild steel (EN3B) work-piece in lathe machine with textured and Non textured cutting tool keeping the feed and depth of cut as constant and varying the cutting speeds. Measurement of forces acting on the tool, cutting tool temperature while machining and comparison of chip size was made. The results exhibit reduction in cutting force requirement and cutting tool temperature in case of textured tool. Chips collected at different speed have been compared and the results showed that textured tool exhibits reduction in chip size. Performance of Textured and non-textured tools were investigated and the results of the experimental study are presented in this thesis.

List Of Publications

- **Shivam Mishra**, Manikandan M, Ankita Sahu, S. Kanmanisubbu, I.A. Palani "Investigation on fabrication of Nickel structure using selective laser melting technique" NLS conference(2018).

- Vinod Singh Thakur , Manikandan M , Shalini Singh , **Shivam Mishra** , Ankit kaithwas , Mani Prabu S S , I.A. Palani "Laser polishing of wire arc additive manufactured SS316L sample" AIMTDR conference (2018).

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NOMENCLATURE

P	**Laser power**
SS	**Scan speed**
n	**Number of passes**
V	**Cutting speed**
N	**Revolution per minute**
f	**Feed**
d	**Depth of cut**
F_x	**Feed Force**
F_y	**Radial Force**
F_z	**Cutting force**
t	**Thickness**

ACRONYM

SLM	**Selective laser melting**
SPCT	**Single point cutting tool**
SEM	**Scanning electron microscope**
XRD	**X – ray diffraction**
EDX	**Energy Dispersive X -Ray Analyzer**
MS	**Mild steel**
HSS	**High speed steel**

Chapter 1: Introduction

1.1 Introduction to Single point cutting tool

Single point cutting tool (spot) is type of cutting tool, which is used for removing material from work piece. Generally single point cutting tool is used for orthogonal cutting, turning and boring operation. Special features of single point cutting tool are rack angle, relief angle, lip angle, nose radius as shown in figure1.

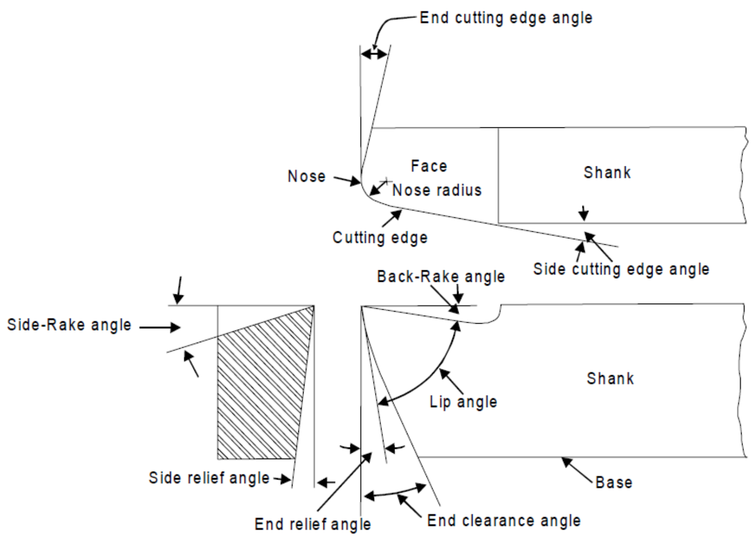


Figure1: Geometry of single point cutting tool

The important aspect in machining is tool life and tool wear to minimize the machining cost. With the use of tools, they are subjected to wear. The tool life means the useful life of the tool, generally expressed in time unit .Different kind of wears in the tool cause reduction in the tool life. Tools are subjected to very high temperature, very high stress and metal to metal contact at tool-chip and tool-workpiece. Because of these severe conditions the tool chip and tool-workpiece interfaces exhibit different kind of wear . As the tool wear progresses ,cutting force and vibration increases. The tool tip softens and gets blunt, which will result in further progressing plastic deformation from tool tip to interior. There are mainly two types of wear found in tools. They are

1.Crater wear: The crater wear occurs on the rack surface of the cutting tool and is generally circular. The crater wear not always reaches to the tool tip, but may end at some distance from the tool tip. It increases the required cutting forces, changes the tool geometry, and softens the tool-tip.

2.Flank wear: Flank wear occurs on the clearance surface of the cutting tool. The wear land can be characterized in terms of length of wear . It changes the tool geometry and cutting parameters such as depth of cut may change .

The presence of crater wear is not of much consequence as far as machining performance is concerned. Initially it may increase the rack angle and hence decrease the required cutting force. However , as the depth increases, friction increases, the chip tool contact length increases and hence the machining performance decreases. Number of wear mechanism has been proposed to understand the tool wear phenomenon, such as adhesion, abrasion, Diffusion and fatigue. Hence the flank wear is caused by abrasion while crater wear is caused by diffusion.

Following are the factors which affect the tool life

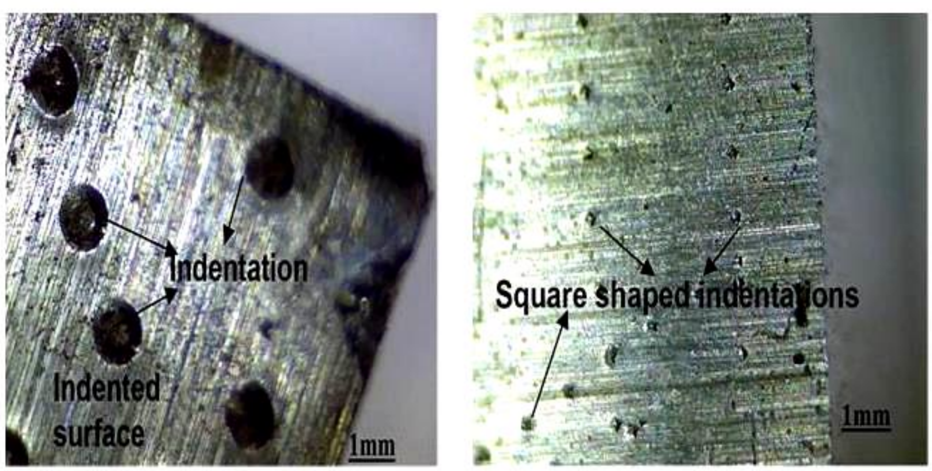
1.Tool material	2. Tool geometry
3.workpiece material	4.Cutting conditions

Various efforts have been made to improve the tool life to minimize the machining cost and to improve the machining performance, such as use of tool inserts, texturing of single point cutting tool etc. [1].

1.2 Texturing of single point cutting tool

In the current time industrialist face many issues while machining and one such major issue is the tool wear and the tool life of cutting tool. This plays vital role in influencing the production process cost. Several methods have been tried and one of the effective method is surface texturing. Texturing the rake face of the cutting tools is promising and environment friendly method for reducing the cutting force and chip size during machining. surface texturing by laser has been the widely used method for making textures on the cutting tools [2,3]. In dry machining operation surface texturing has the potential to improve the tribological conditions at the tool-chip interface and the surface texturing on cutting tool surface improves the machining performance[4,5]. Texturing of the cutting tools improves machining performance in machining of different materials by reducing the temperature of machining zone, decreasing cutting force requirement , and reducing the wear of the cutting tool[5].

Texturing is surface modification process to achieve some specific objective. Texturing in surface can be done in two ways, One way is to deposit some material on the surface which is termed as positive texturing and another is to remove material from the surface, which is termed as negative texturing. So texturing can be done by making grooves, scratches or by depositing material. Surface texturing has been done on both the rack surface and the flank surface of the cutting tool to know the tool wear rate and performance. Since the tool life is mainly influenced by rake surface so there is not much consideration for texturing in flank surface.



(a) (b)

Figure2: Negative texturing in tool rack surface (a) Textures by Rockwell hardness tester (b) textures by Vicker hardness tester [5]

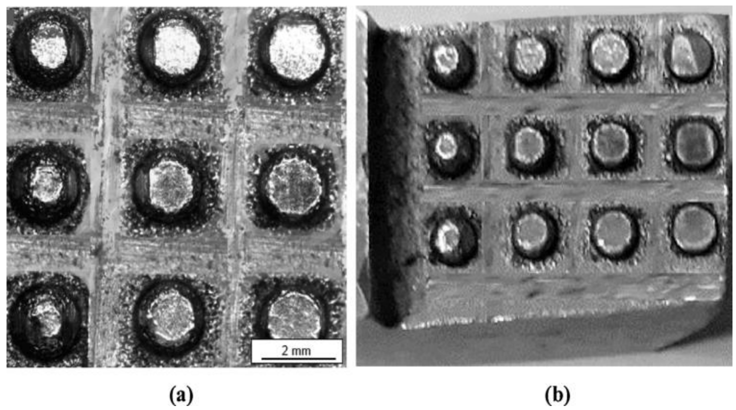


Figure3; Positive texturing by spots deposited on rack surface by micro plasma arc powder deposition method [4]

The purpose of positive texturing is to reduce the chip-tool contact area. The positive texturing in rack surface increases the curvature of the chip and hence acts as chip breaker. The reduction in chip tool contact length results in decrease in friction force and hence cutting force requirement also decreases.

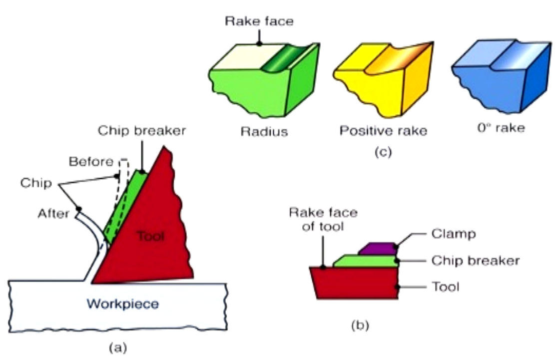


Figure4: Working of chip breaker [12]

The figure shows working of chip breaker which increases curvature of chip and breaks it earlier. Previous works on texturing shows that at higher cutting speed Positive texturing is more effective than negative texturing.

1.3 Texturing in tool surface using laser power

Conventional and advance manufacturing process both are in use in today's time as both offer their own advantage Both these process apply different method for producing same product but the product is different in shape and mechanical properties. Usually in advance manufacturing process better surface finish and dimensional accuracy can be obtained as compare to conventional manufacturing process. In advance manufacturing process there is no contact between tool and work-piece so there is minimum probability of having defect or any unwanted effect on product. The texturing in the tool surface can be done in two ways using laser power .One way is to make micro scale dimples by laser which is negative texturing and another way is to deposit a material on rack surface using selective laser melting process, which will create positive textures on the rack surface. The positive textures deposited by SLM acts as chip breaker and also reduces friction on the chip-tool interface.

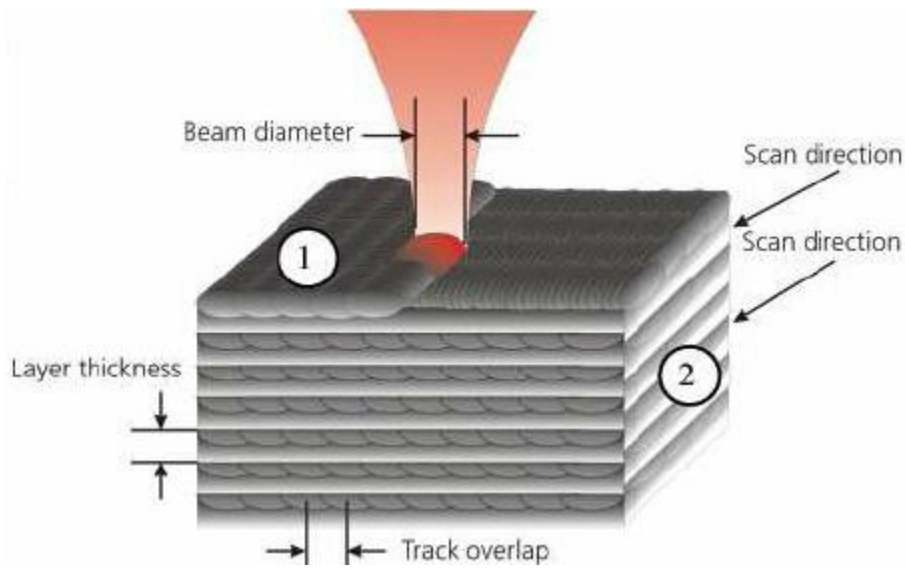


Figure 5: Process of selective laser melting [14]

Selective laser melting (SLM) produces parts by fusing together successive layers of powder material. The main benefit of the SLM is that it is able to process a very wide range of materials (standard polymers, metals, ceramics, foundry sand, etc.), and yields excellent material properties (i.e. close to those obtained with other manufacturing methods)[6]. In selective laser melting, the metal to be processed is taken in powder form. A high-energy laser power locally melts the fine metal in powder form. The component made by SLM is then cleaned and is taken out from powder bed. Moreover, the components made by laser power are high in density and strength& component possess good mechanical properties too. So because of these advantages SLM can be very useful method for positive texturing in single point cutting tool.

1.4Motivation

Tool life and tool wear are the two important aspects in machining operation. Tool wear affects the machining performance such as, cutting force requirements, surface finish in workpiece and tooling cost. To reduce the machining cost we need to use hard tool material but it should not be very costly. So to optimize the machining performance and tool cost various solutions have been tried and texturing of tool is one of those methods. Texturing has been effective method for reducing cutting force requirement and chip size. Texturing also restricts the temperature rise in the tool so tool wear is also minimized. Positive texturing (deposition of material on surface) gives added advantage in reducing the chip size. Positive texturing acts as chip breaker in rack surface and hence reduces the chip size and cutting force requirement.

The challenge in case of positive texturing is adhesive strength of deposited material on the rack surface. The stellite deposited by micro plasma arc method shows the same issue as the material at the interface do not possess much strength as the material deposited on rack surface should be able to withstand the force applied by the chip while machining. The better adhesion on the rack surface can be obtained by using laser power. Use of laser power allows to use wide variety of material for texturing of single point cutting tool as most of the metals can be melted under laser power. The height of texturing material on the rack surface can be optimized in case of laser based positive texturing of single point cutting tool to improve the tool life and machining performance.

1.5 Research methodology

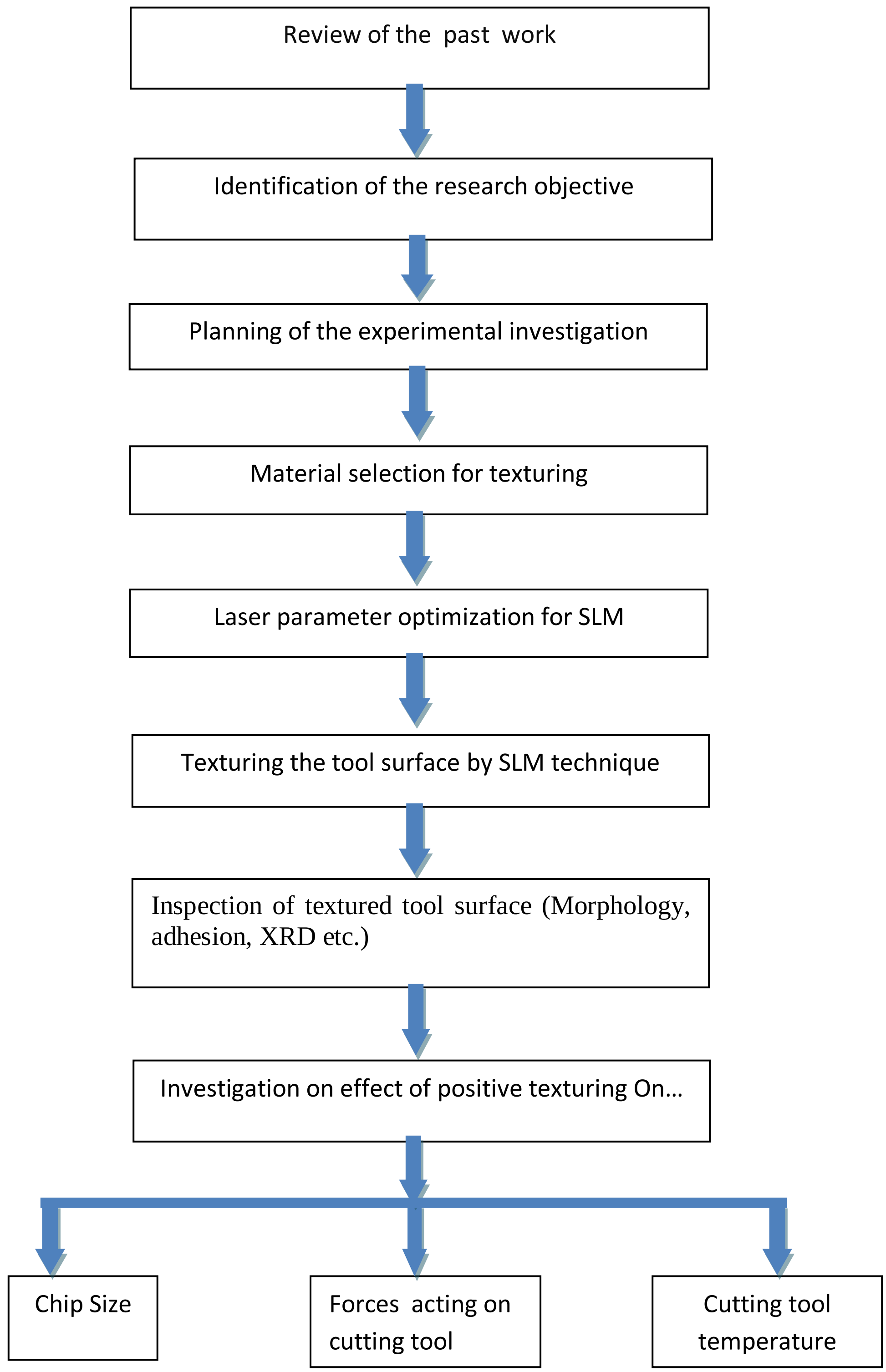


Figure6: Research methodology used in present work

1.6 Research Objective

Various research objectives of this research are as follows

- To reduce chip size in turning operation by positive texturing on the rack surface ,which acts as chip breaker .
- To reduce the contact area between chip and tool so as to reduce the friction force which in turn reduces the cutting force.
- To decrease the tool temperature to prevent the tool wear by better heat dissipation by positive textures on the rack surface.

Chapter2: Literature Review

2.1 Past Work On texturing of single point cutting tool

S.Jesudass Thomas & K. Kalaichelvan[5] have studied effect of texturing in cutting tool. They have textured cutting tool using Rockwell hardness tester for making conical dimples on rack surface, vicker hardness tester for square dimples and diamond dresser and steel ruler for making scratches in rack surface. They have compared the textured tool and non-textured tool on the basis of cutting tool temperature after cutting, change in chip size and cutting force required .Following conclusions they have drawn from their study

- Out of these three types of texturing, texturing by Vicker hardness tester results more reduction in cutting forces.
- For aluminum workpiece, reduction in cutting force required was 41.2%, 38.5%, and 21.9% for feed force ,radial force and cutting force respectively. For mild steel work-piece, cutting force was reduced by 20.79%, 18%, and 12.92% for feed force ,radial force and cutting force respectively.
- The reduction in cutting tool temperature in case of textured tool for Aluminium work-piece was found to be 3.28% whereas this reduction for mild steel workpiece was found to be 12.85 %.
- The texturing in rack surface affects the chip formation. The chips formed while machining Aluminium by tool textured by Vickers hardness tester, were in wire from and coiled in shape. In case of mild steel rod, texture created by Vickers hardness tester, acts as chip breakers and reduces the tool–chip contact length.

Mayur S. Sawant [4] has studied effects of both dimple texturing and spot texturing in cutting tool. In this research they have done texturing by micro plasma arc method. They have compared the performance of textured and non-textured tool on the basis of change in chip size, flank wear, cutting tool temperature and cutting for requirement. They concluded that spot textured tool has resulted in least value of thrust force and cutting force, cutting tool temperature, average surface roughness of workpiece after turning. They have observed that texturing in tool is more effective while turning at higher speed. Spot-textured HSS tool in turning of Ti-6Al-4V resulted in minimum values of cutting and thrust forces, cutting tool temperature, flank wear and surface roughness of work-piece than the dimple-textured and non-textured HSS tools at different values of cutting speed. Performance of the dimple-textured HSS tool is better than the non-textured tool in these investigations.

S. Niketh [22] has conducted the experiments to investigate the effectiveness of micro-textures in reducing sliding friction at the contact surfaces and it's application on drill tools for the sustainable machining of Ti-6Al-4V.They have created micro textures on both the flute and margin side of the drill tools with an objective to minimize the cutting forces by reducing the sliding friction at the tool-chip and tool-work piece interfaces. Micro textures in the form of dimples were created on the flute and margin side of drill tool using laser micromachining technique. Drilling experiments were performed on Ti-6Al-4V work material by drilling a through hole of 10 mm depth using non-textured, flute textured and margin textured tools. From the cutting forces recorded during machining, it was observed that even at the higher cutting speed of 60 m/min and feed 0.07 mm/rev, the margin textured tool performed better than all other tool types recording a net reduction of 10.68% in thrust force and 12.33% in torque compared to non-textured tools. The investigations on the chip morphology further revealed less clogging of chips in case of flute textured tool which is a clear indication of a reduction in the chip evacuation force. The experimental results from this research work proved micro texturing of drill tool to be a viable technique for minimizing the energy loss due to reduction in frictional forces at the cutting regime while machining Ti-6Al-4V.

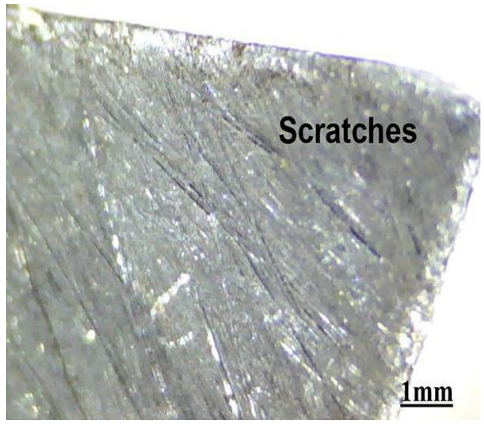


Figure7: Textures made by Diamond dresser and steel ruler [5]

2.2 Past work on selective laser melting

Chor Yen Yap [8] has studied on selective laser melting in nickel powder. To characterize the sample micro-harness and tensile strength in sample were measured. They observed that scan speed and hatch spacing has significant effect on porosity of samples. High relative density of 98.9% was observed and micro hardness was obtained 140HV to 160 HV. The tensile strength of sample was observed to be 452 MPa.

Following conclusions were made-

- Nickel powder of particle size 90 μm to 45 μm can be successfully processed with SLM.
- Good interlayer bonding was observed with lesser porosity in microstructural analysis.
- The grain size in sample fabricated by SLM varies between 15μm to 100μm.

[28**] Ruidi li** has studied balling phenomenon which is a type of defect ,in selective laser melting process of Nickel powder. In his research he found that balling phenomenon can be divided into two types such as: the elliptical balls with dimension of about 500 am and the spherical balls of dimension of about10 µm. The ellipsoidal balling is caused by worsened wetting ability and decreases SLM quality; the spherical has not much effect on SLM quality.

[29]**LykovP.A.** has performed the experiment for selective laser melting of Copper powder. They have fabricated five 10mm×10mm×5mm samples by selective laser melting of copper powder by varying different parameters like scan speed, exposure time and scanning pattern. The structure of fabricated sample was studied by scanning electron microscopy of polished cross sections. The tensile test was carried out for SLM fabricated sample with the lowest porosity.

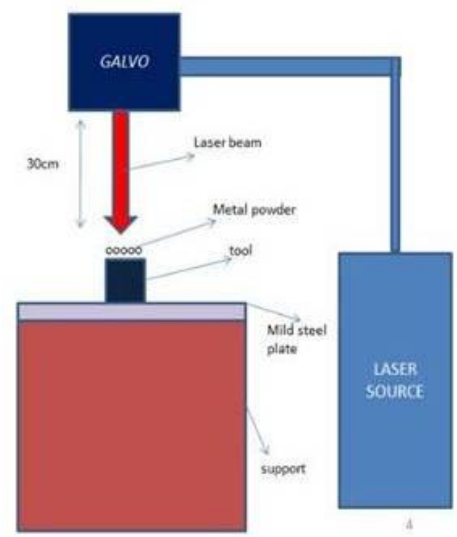
Chapter 3 : Experimental setup

3.1 Details of experiments

Ytterbium (Yb) doped continuous fiber laser machine is used as a source of power for melting the metal powder. The wavelength of laser used is 1064nm and focal length is 30cm .To analyze melting response of different powder we have used different metal powder under laser (i.e. aluminum, copper and Nickel powder).The powder is kept in a mild steel plate and then exposed to the laser for melting. There are various laser parameters which affect the sample fabricated by SLM, out of these there are three parameters that has significant effect on sample fabricated by SLM and these are laser power, scan speed and number of passes. Among these parameters we have varied one parameter while keeping the other parameters constant. The process is carried out in open environment.

Experimental setup for texturing

(a) (b)



a) Continuous laser machine b) Schematic diagram for texturing

Figure 8: Experimental setup for tool texturing

Controlling unit

Following are the switches in control panel to control laser machine

a.) Galvo On/Off
b.) Laser On/Off
c.) PC On
d.) PC Reset
e.) Laser enable/Disable
f.) Rotary Enable
g.) Z-axis Up/Down

Figure9: Controlling unit of the continuous fiber laser

SciTech software is used in which the shape which we want laser to scan is given in it and then other parameters like laser power, scan speed, Number of passes, pulse width, output period and jump delay can be set.

3.2 Experimental set up for turning

Figure10: Experimental setup for turning

Figure shows experimental set up for turning operation by single point cutting tool. The high speed steel tool (HSS)is used for turning mild steel bar of 30cm length and 30mm diameter. The HSS tool which is supplied by Miranda tool as grade of S400 is chosen because of its higher hardness as well it is cheaper than carbide tools. HSS tool can be economical tool material if its wear is minimized by proper surface texturing. The tool was imparted with 17° end relief angle, 15° as end relief angle and zero degree back rack and side cutting edge angle both. On the prepared tool, positive texturing is done by SLM process with Nickel powder and the tool is then used for turning the mild steel(EN3B) bright bar. The operation is performed in lathe machine and for measuring different forces acting on tool, Kistler force measurement dynamometer is used. Dynamometer measures all forces that act in turning operation i.e. cutting force, radial force and feed force. The experiment is performed without lubricant and aim was to analyze effect of texturing in dry machining operation. Machining parameters like feed depth of cut and cutting speed has been chosen from literatures.

Chapter 4: Selective laser melting and parameter optimization

4.1 Selection of Material for Texturing

4.11 Selective laser melting with Aluminium powder

Effect of parameters

We have used Aluminium powder for selective laser melting. We have varied different laser parameters and their effect on Aluminium was observed. Laser power is varied from 35 watt to 10 watt and scan speed is varies from 1 mm/sec to 0.10mm/sec and number of pass we have varied from 1 to 7. Out of all parameters we have listed some important parameters in table1. From experiment we observed that at power 50W to 25 W no significant melting is observed and there is no adhesion among aluminum particles .And while using low power from 20W to 15 W some fusion is observed in Aluminium powder. The reason of this fusion is partial melting due to heat input in Aluminium powder. Optimum sintering is observed at scan speed of 0.15 mm/sec. On increasing the scan speed the heat input is less so extent of fusion decreases while on decreasing scan speed further sample is getting discontinuous due to more thermal gradient in sample. The better sample is obtained for 5 number of laser pass. On decreasing number of passes the heat input is lesser and on increasing number of passes the sample is deformed due to thermal contraction.

Range of parameters used- For rectangular sample of dimension (10mm×4mm)

Power = 35W to 10W

Scan speed = 1mm/sec to 0.10 mm/sec

Number of passes= 1 to 7

Table 1: Important parameters in SLM of Aluminium

S.No.	Power (W)	Scan speed(mm/sec)	Number of passes	Remarks
1	35-25	0.30	3	No melting
2	20	0.30	3	Some sintering is observed
3	**15**	**0.15**	**5**	Fragile “I” shape sample formed

Thus the sample obtained at 15W is better in dimension and regular in dimension but it lacks the strength and is fragile in nature. Hence from our experiments we can conclude that Aluminium is difficult material to be processed under laser power and it can not be melted under lower laser power irrespective of the other parameter like scan speed and number of passes.

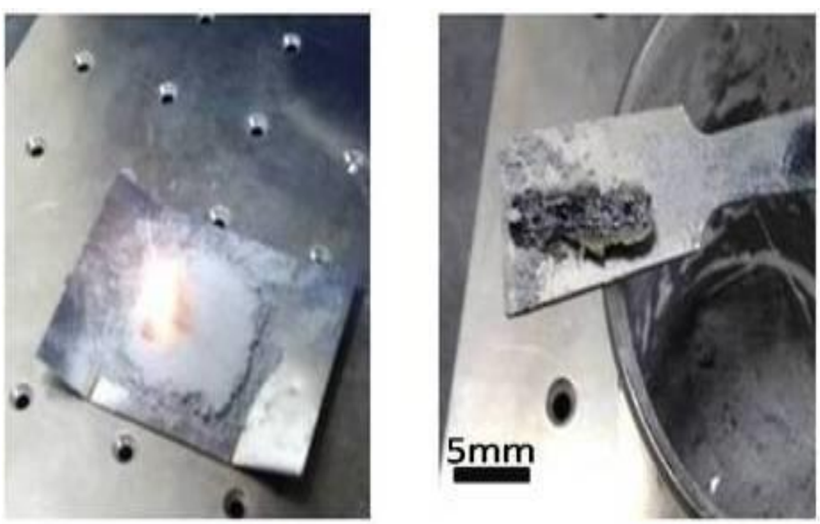


Fig11: SLM of Al at P =25W, SS = 0.30mm/sec, n=2

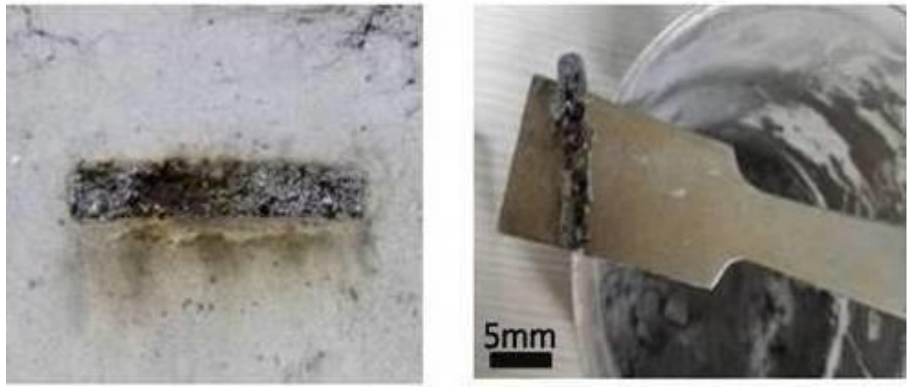


Fig12: SLM of Al at P=15W, SS = 0.30mm/sec, n=2

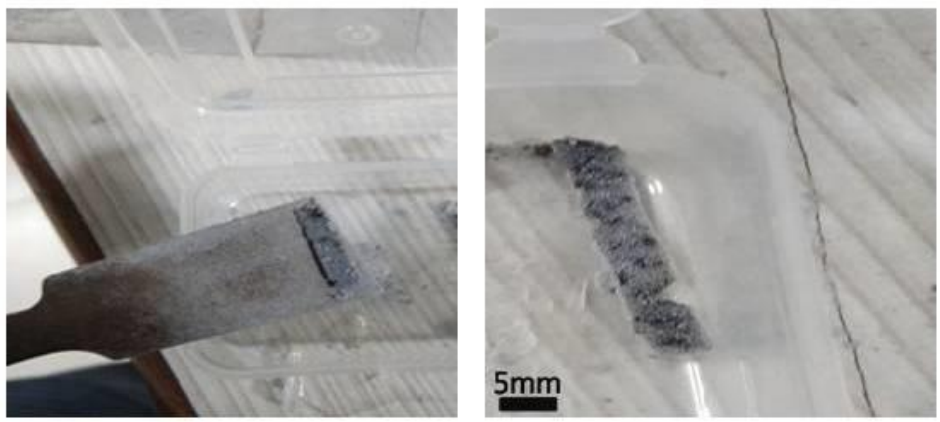


Fig13: SLM of Al at P=15W, SS = 0.30mm/sec, n=5

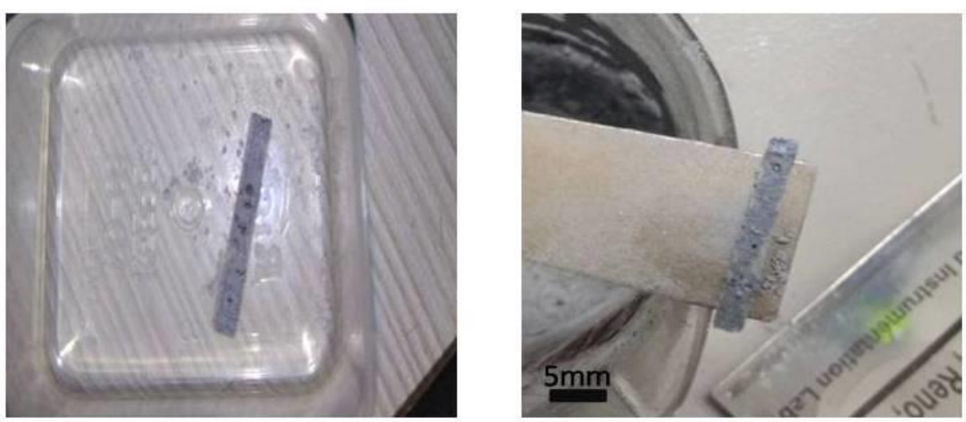


Fig14: SLM of Al at P =15W, SS =0.15mm/sec, n=5

At optimized parameter, sintering is observed in aluminum powder but the sample so obtained is brittle and fragile in nature.

4.12 Selective laser melting with Copper powder

After Aluminium we have tried selective laser melting with copper powder .We have varied power from 40 watt to 15 watt. Between 50W powers to 25 W powers, no significant melting is observed .But at lower laser power 20W -15W some fusion is observed among copper particles in copper powder. Scan speed is optimum at 0.15 mm/sec with 2 number of passes. On increasing number of passes due to thermal contraction sample starts bending from ends. Sintering speed is calculated for rectangular sample of dimension (10mm×4mm).

Table 2: Important parameters for SLM of Copper

S.No.	Power(W)	Scan speed(mm/sec)	Number of pass	Remarks
1	40-25	0.30	3	No melting
2	20	0.15	2	Fragile “I” shape sample formed
3	15	0.15	3	Fusion but not continuous

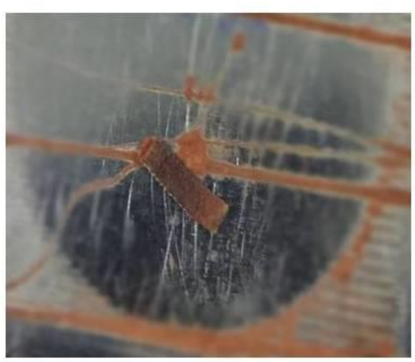


Fig15: SLM of Cu at P =15W, SS =0.30mm/sec, n=2

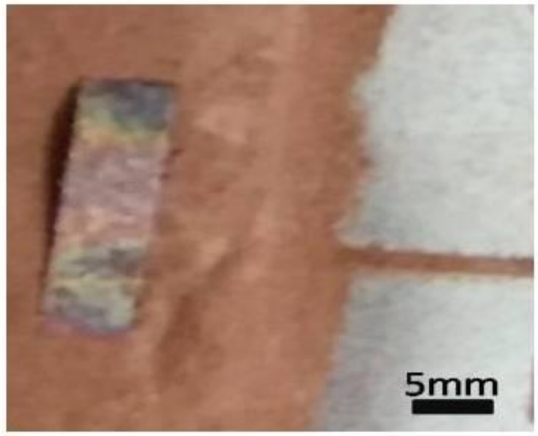


Fig16: SLM of Cu at P=15W, SS =0.15 mm/sec, n =2

The sample obtained with copper paste was fragile but it is better that the Aluminium sample in terms of strength .Since at higher power ,powder was getting removed when laser strikes it so we have also tried with copper powder with some binder. We made copper paste by adding polyvinyl alcohol with copper powder along with some drops of water .But in copper paste also no significant melting is observed.

4.13 Selective laser melting with Nickel powder

We have used nickel powder for selective laser melting. Upon putting under it was observed that unlike copper and Aluminium, Nickel can be melted under low power laser also. In order to know optimum power at which melting is better we have varied parameter from 50W to 15W keeping scan speed 0.30 mm/sec and number of passes as constant. In figure we can see Uniform melting is observed at 50W and when we decrease the power extent of melting is decreased and on further decreasing power ,no melting is observed at 15W. Although we can attain good melting at lower power up to 30W by decreasing scan speed and increasing number of passes but on increasing number of passes ,due to thermal gradient sample starts bending from ends. Sintering speed is calculated for sample of dimension (10mm×4mm).

Table 3: Parameter optimization for SLM in Nickel

S.No	Power(W)	Scan Speed (mm/sec)	No of Passes	Remarks
1	50-40	0.30	1	Uniform melting
2	30	0.30	1	Extent of meting decreased
3	20	0.30	1	Extent of meting decreased
4	15	0.30	1	No melting

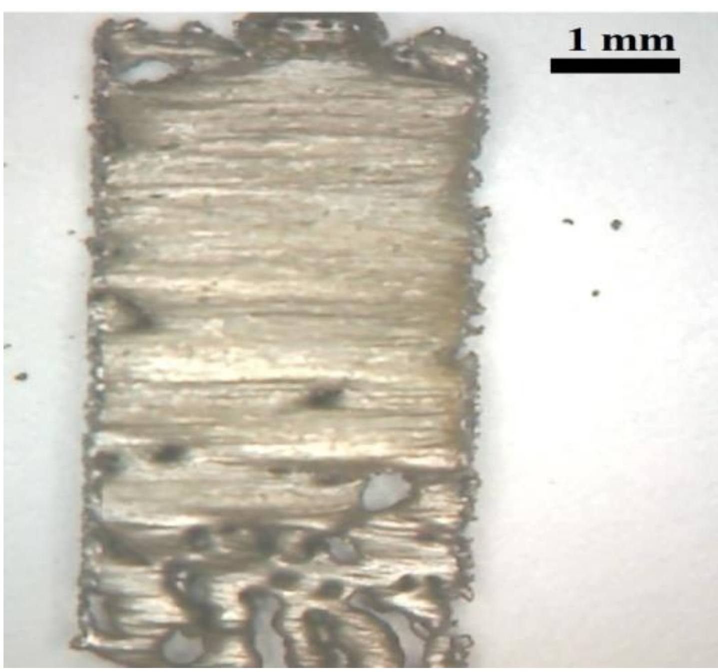
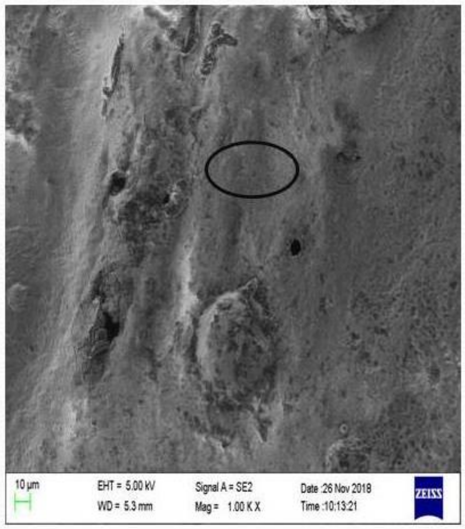


Figure17 : SLM of Ni at P =50W, SS=0.30mm/sec, n=1

Figure 17 shows the sample of Nickel prepared by SLM process at 50W power , SS=0.30 mm/sec and single layer .The SEM image of this sample is shown in figure 18 and EDX analysis is also done. EDX analysis shows the presence of carbon which indicates some burning is there and 19.54 % oxygen presence shows that some oxide formation is there, which is because the process has been carried out in open environment.



ELEMENT	WEIGHT (%)
C	8.20
O	19.54
Ni	72.26

Figure 18: SEM image of Ni sample at 50W made by SLM

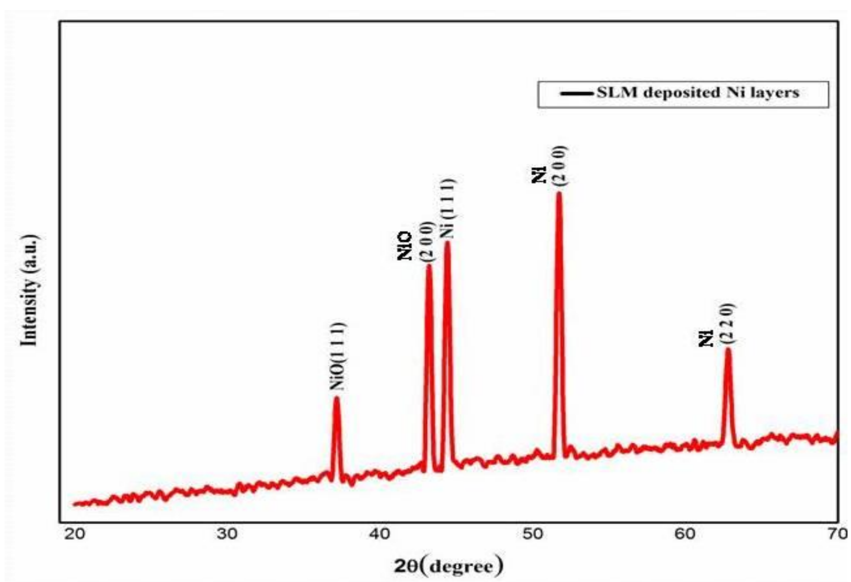
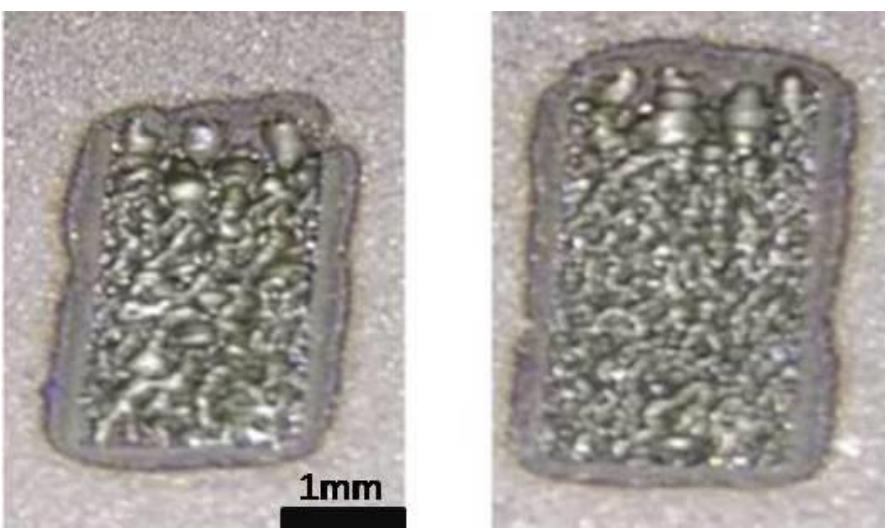


Figure19: XRD analysis of Ni sample made by SLM

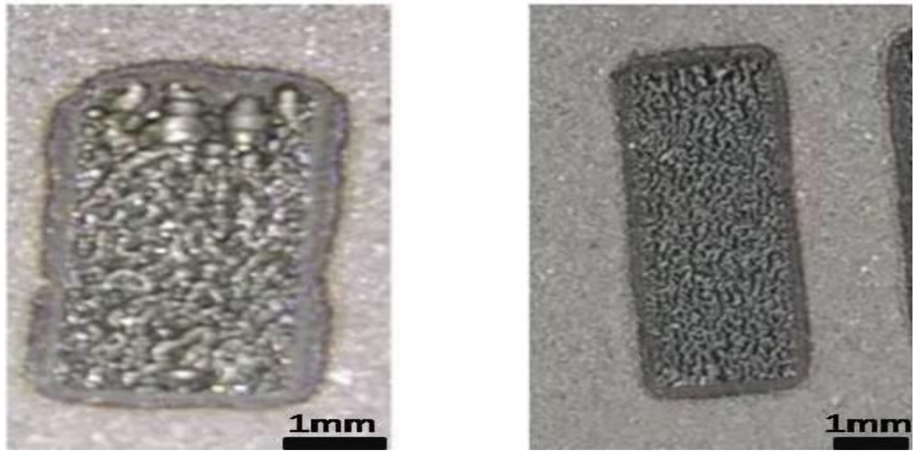
The figure 19 shows the XRD analysis of Ni sample fabricated by SLM as shown in figure 17. From XRD analysis it is clear that different oxides of Nickel like Ni_2O_3, NiO and pure Nickel is present in the sample.

Figure20: SLM of Ni at P=45W, SS= 0.30mm/sec, n=1



(a) (b)

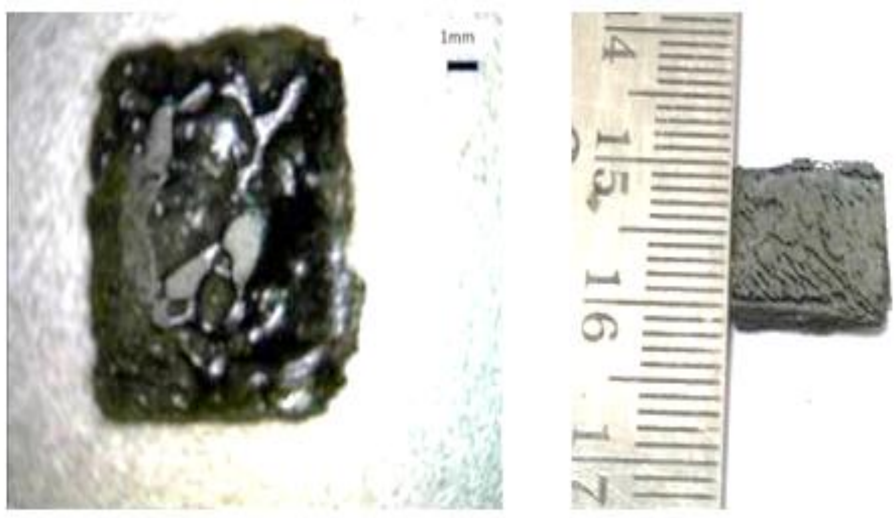
Figure 21: SLM of Ni at (a) 40W (b) 35W



(a) (b)

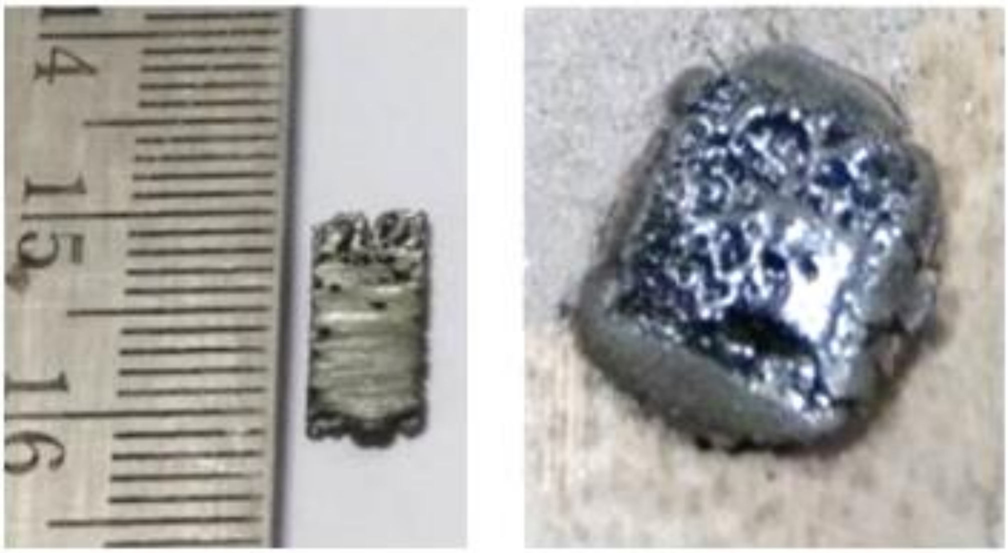
Figure 22: SLM of Ni at (a) 30W (b) 20W

From above figures it is clear that uniform melting is observed at 50W with scan speed 0.30 mm/sec and single laser pass. Then we have increased the thickness of sample by pouring powder layer by layer .We have made sample up to 8 mm thickness. Figure23,24 show the Nickel samples Fabricated by selective laser melting at parameters power=35W , SS=0.15 mm/sec, n=3 .The scan speed is measured for the sample of (10mm×10mm).



(a) (b)

Fig 23: Ni sample prepared by SLM (a) t=8mm (b) t= 4 mm



(a) (b)

Figure24:Samples made by SLM (a) Thickness t=2mm (b)t = 6mm

From experiments we come up to conclusion that as the thickness of the sample increases the uniformity of sample decreases. From figure 23,24 we can see that for the sample with thickness 4 mm ,sample is square in shape but the sample with thickness 8mm and 6 mm, dimensions are not uniform.

It can be observed that laser power, number of passes and the scan speed play a major role in affecting the structure of the final component. From optical image it is clear that complete melting of nickel has occurred at 50-watt power whereas complete melting was not obtained when we keep power below 35 watt. In this work, Ni structures possessing enough strength have been fabricated successfully using SLM technique.

Surface Morphology The surface morphology of the fabricated Ni samples was characterized using optical microscope. The Fig.25 shows the surface morphology of SLM fabricated SLM samples. It clearly depicts that melting has happened throughout the surface of the samples and no traces of unmolten powder is visible.

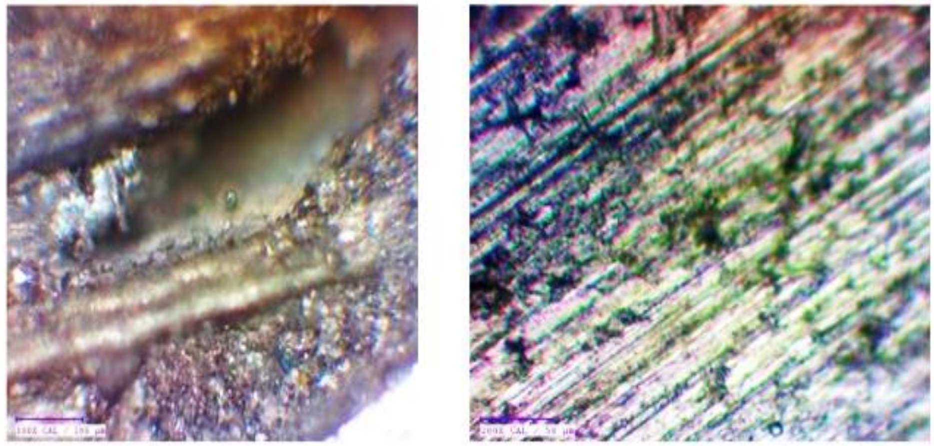


Figure25: Surface morphology of Ni sample (fabricated by SLM) by optical microscope.

4.2 Material Selection and Texturing of single point cutting tool

Material selection- The material used for positive texturing of cutting tool should have high melting point as well as good laser absorption capacity. Moreover the material should have good thermal conductivity so that it can dispose off the heat from machining area. The melting point of material should be comparable with that of tool due to which better adhesion is obtained between molten metal and tool surface. For these characteristics we have tried different metal powder like copper, aluminium and Nickel. From our experiments and literature we can conclude that Copper and Aluminium both have less laser absorption coefficient and are difficult to process under selective laser melting process. Moreover the melting point difference between metal and tool material makes the adhesion of metal on tool more difficult. Further we have used Nickel powder for positive texturing in cutting tool ,which can be successfully processed under selective laser melting process at lower powers also. Nickel has been proven to be a feasible material for processing with SLM. The melting point of the Nickel is 1455°C which is closer to that of HSS tool (1422°C) hence during SLM there is partial melting in both metal and tool , which results in fusion of molten metals and gives stronger adhesion between metal and tool which can sustain the force exerted by chip and acts as chip breaker. For the above mentioned advantages offered by Ni, we have chosen Nickel as material for positive texturing of single point cutting tool.

Positive texturing in cutting tool -The texturing of single point cutting tool is done by selective laser melting of Nickel powder. From experiments we have seen that Nickel powder can be melted under low laser power. The challenge in texturing the tool surface is the adhesion of Nickel on the tool surface.

- Range of Parameters used for texturing

  Power = 15W to 50W

  Scan speed= 2mm/sec to 0.10mm/sec

  Number of passes= 1 to 4

The texturing in tool is greatly influenced by laser power. On using higher power from 50W to 25W the laser beam removes the metal powder from the rack surface, despite of varying the scan speed. But on reducing power to 20W , laser doesn’t removes the powder and Ni powder melts on tool surface but the adhesion between tool and molten nickel is not that strong. As shown in figure 26.

Figure26: Texturing At P=20 W and SS=0.30mm/sec, n=1

Further on reducing scan speed to 0.20mm/sec better adhesion was observed on tool.

To improve the adhesion one way is to make surface little rough and that will prevent the powder to move and helps in adhesion. This roughness we have created in rack surface by passing laser beam on it. For ablation we have used laser beam of 30W power at 0.20mm/sec for 3 passes.

Figure27: Deposited Ni on the tool surface

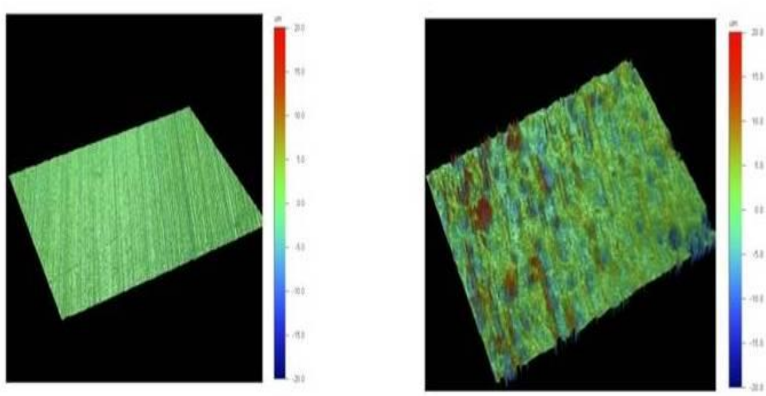


Fig 28: a) Non textured tool surface b) Textured tool surface

Along with laser power,scan speed, and number of passes one more parameter is there, which plays important role in texturing , and that is focal length. The focal length of the laser machine is 30 cm. Since at focal length at higher power beam removes the powder from tool surface hence we changed it and on increasing the focal length this problem gets solved. The increase in focal length allows us to use higher power. The optimum focal length is 32cm. After texturing to check adhesion between tool and Ni , we have cut the tool in wire edm machine. The textured tool surface is shown below in figure 29.

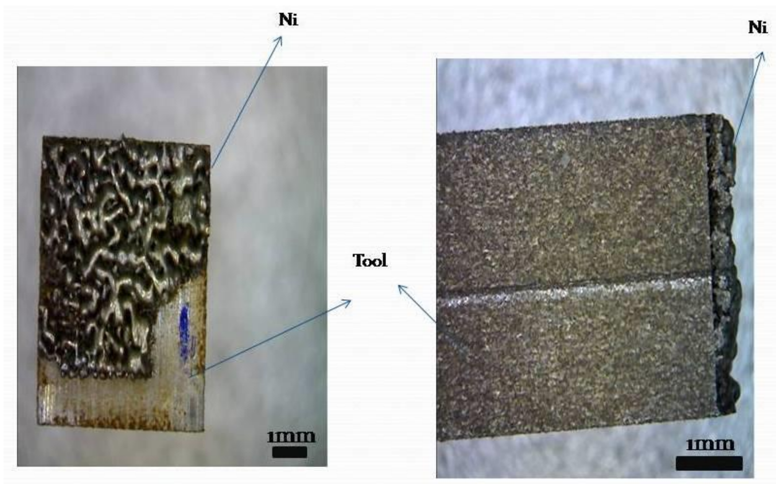


Figure29: Textured tool surface

4.3 Summary

Thus it can be concluded that Aluminium and copper require higher laser power for melting and can not be melted at lower power irrespective of scan speed and number of passes. Whereas Nickel powder is successfully melted at lower laser power also.Although uniform melting is obtained at 50W power but Ni can be melted at 20W power also by reducing scan speed and by increasing number of passes. We have chosen Ni as texturing material for positive 0texturing of single point cutting tool and it is successfully deposited on the rack surface of the tool.

Chapter 5: Results & discussion

5.1 Effects of parameters

There are various laser parameters which affect the SLM process but out of these three parameters are more significant and these are laser power, scan speed and number of passes. From experiments we can observe that higher laser power gives better deposition on tool surface for the reason that it results in partial melting of tool and metal powder and then due to fusion between both molten metal, bond is formed. On the other hand scan speed also plays important role in adhesion of nickel on tool surface. As on increasing scan speed the heat input is less and it results in weaker adhesion whereas if we decrease the speed more, it causes temperature gradient in rack surface due to which strength of deposition is different at different spot. Number of passes also alters the nature of deposition. On using lesser power we need to increase the number of passes but at higher power better deposition is obtained at single pass and on increasing number of passes it causes re-melting of deposited material and makes adhesion weaker. The scan speed is measured for spot of (9×9) mm.

Table 4: Optimized parameters

S.No.	Power(W)	Scan speed (mm/sec)	Number of passes	Focal length(cm)
1.	50	0.20	3	32

5.2 Optical Microscope Image

The optical microscope images were taken at the interface of tool and deposited Nickel to analyze nature of deposition at interface. From image it is clear that there is melting of both, tool as well as Ni powder and these molten metals have fused together to make a bond. The upper part in image represents the tool rack surface while lower part represents the deposited Nickel

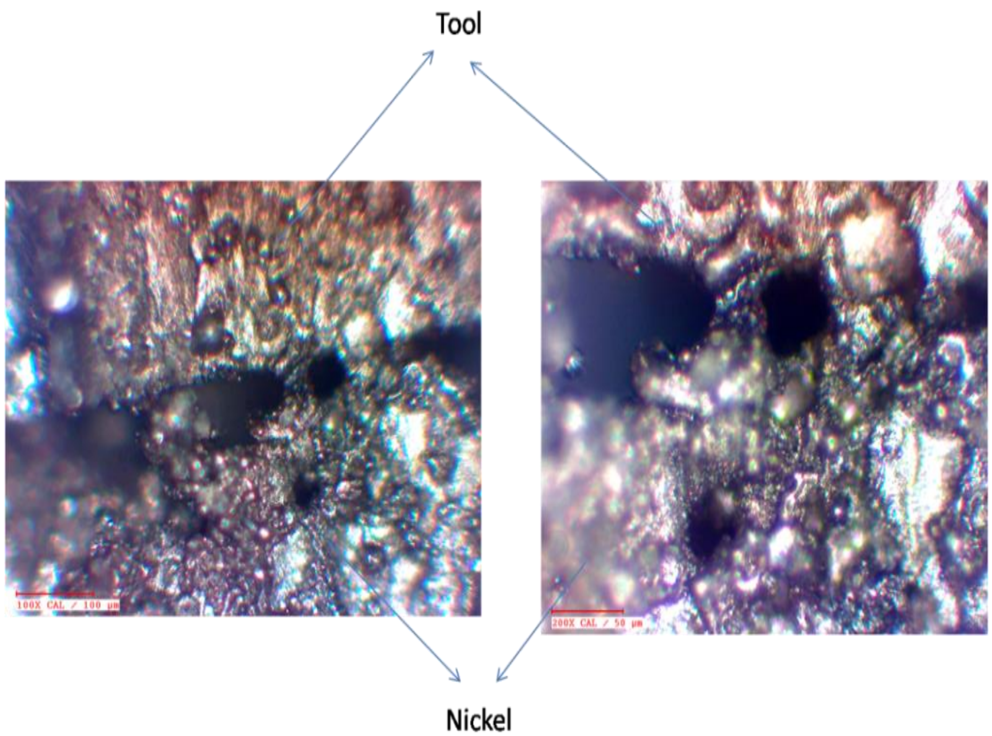


Figure 30: Optical microscope image at Ni-tool interface

5.3 Optical surface profile

Optical surface profiler was used to analyze textured tool surface after deposition of Nickel and it was observed that height of peaks varies from 5.14µm to 26.06µm. Average height of Ni peaks was obtained as 6.20µm.From fig. we can see the deposited Nickel peaks. The Roughness of the surface does not refer to height of Nickel spots rather it represents roughness in plane of textured part

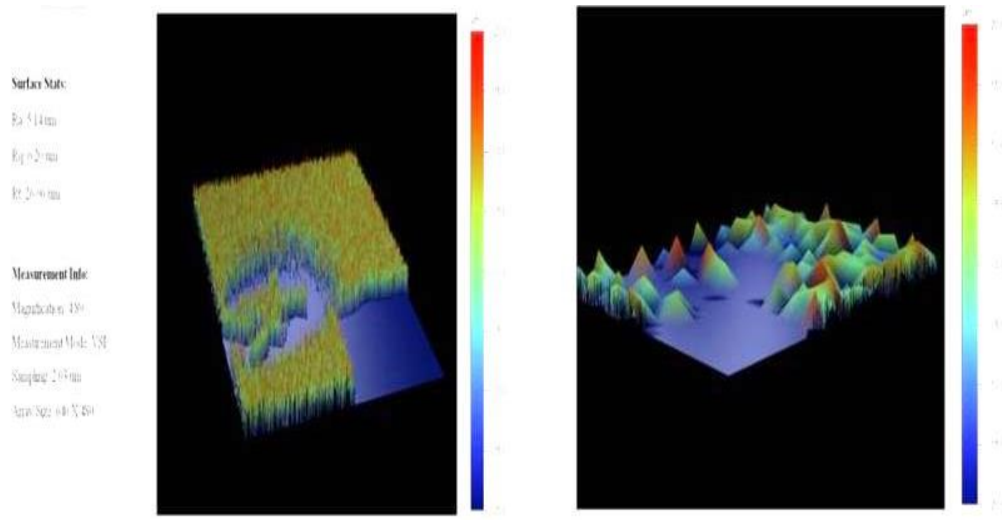


Figure 31: Optical 3D surface profile of textured rack surface

The figure 31 shows the 3D profile of the rack surface of single point cutting tool. The roughness and peaks on the rack surface are the deposited Nickel which acts as positive texturing. Although the height of textured spots should not be much because then these spot will act as negative rack surface and increase cutting force. The aim of spot texturing is to deflect the chip and reduce the chip size.

5.4XRD analysis

The textured surface was analyzed under XRD technique. From XRD analysis of textured surface of cutting tool it is clear that there is formation of oxides of Nickel which is because process of texturing is carried out in open environment. The peaks of XRD confirm the presence of NiO and pure Ni. The peaks are observed at angle 44.3° (Ni), at 55 ° (NiO) and at 77.5° (NiO).

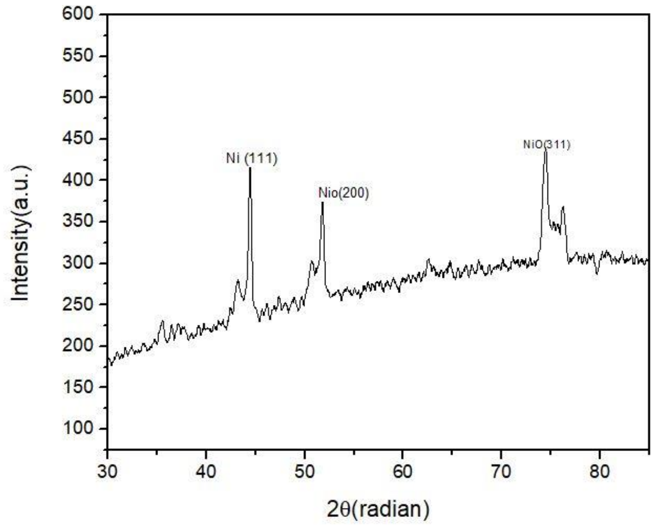


Figure32: XRD analysis of textured surface of cutting tool

5.5 SEM&EDX analysis

Scanning electron microscope has been used to analyze surface morphology of textured surface of tool. The SEM image confirms that there is uniform melting of nickel powder and from EDX analysis weight % of nickel, oxygen and carbon is determined. EDX analysis shows that Ni is present 40.68% (wt. %) and oxygen present is 38.46 % (wt. %) where as carbon is also present 20.68 %(wt. %).

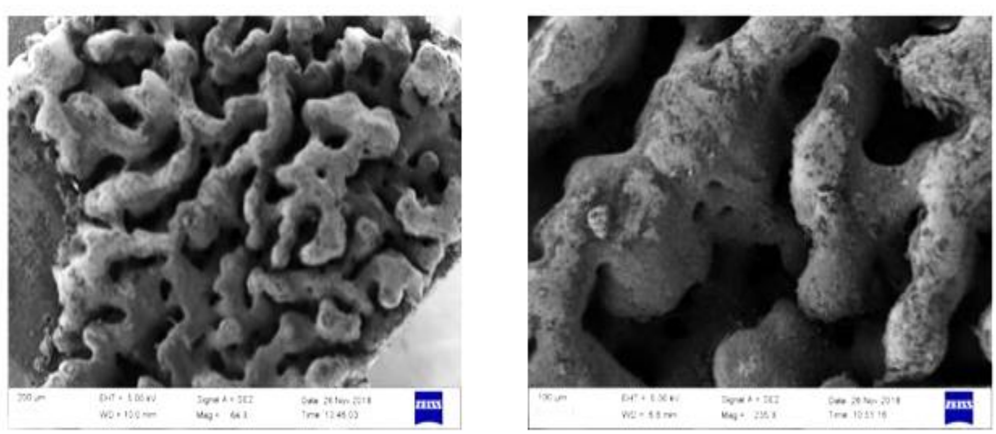


Figure 33: SEM images of textured surface of cutting tool

Table 5: EDX analysis of textured tool surface

Element	Weight %
Ni	40.68
O	38.46
C	20.86

5.6 Effect of texturing on chip size

Chip size affects dynamics in machining, tool wear, and tool life. The texturing on rack surface of cutting tool acts as chip breaker and it can be clearly observed as shown below in figure. The experiment was conducted varying the cutting speed from 30 m/min to 50 m/min and keeping feed and depth of cut as constant .From figure 34 it is clear that as speed increases, the reduction in chip is more significant whereas at low speed, not significant difference is observed.

NON TEXTURED **TEXTURED**

Figure34(a): chip Size at V= 30 m/min, f=0.14 mm/rev, d =0.5mm

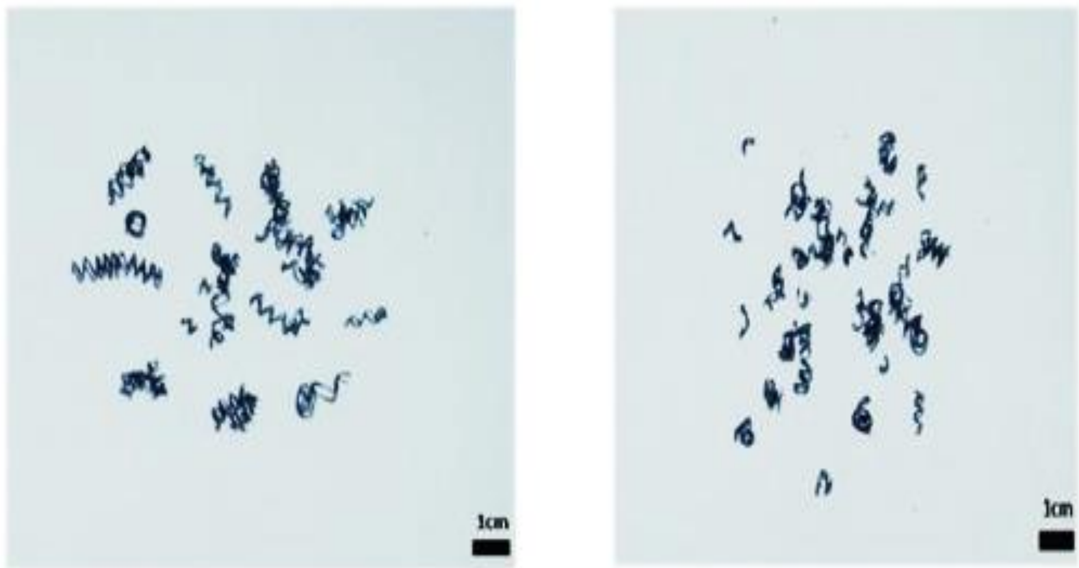


Figure 34 (b): Chip size at V=40m/min, f =0.14 mm/rev, d =0.5mm

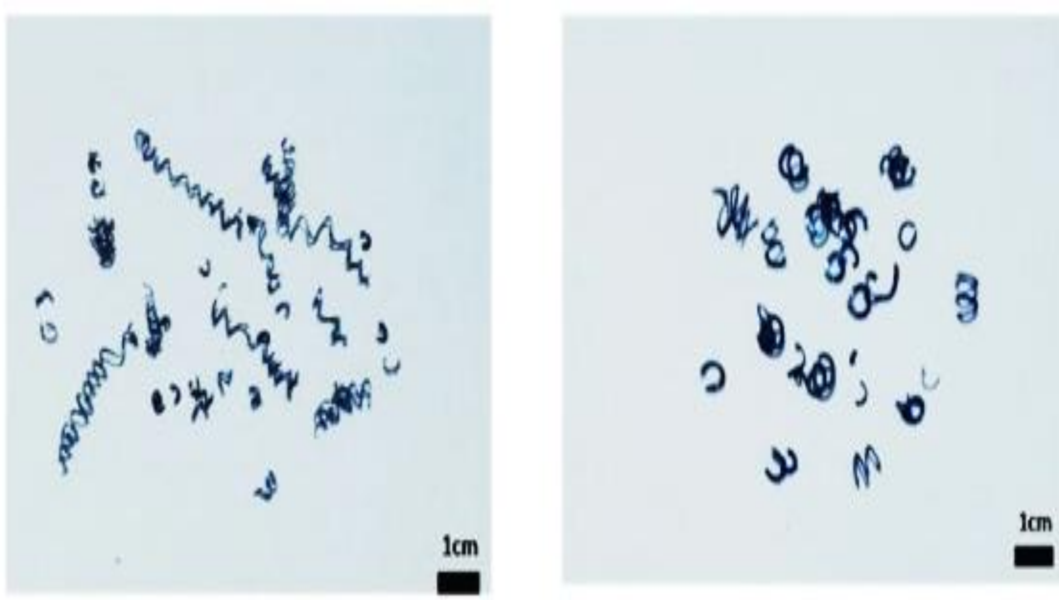


Figure 34 (c): Chip size at V= 50(m/min), f =0.14 mm/rev, d =0.5mm

5.7 Effect of Texturing on the Forces Acting on the Tool

To investigate the effect of texturing on rack surface of tool, turning operation is performed on mild steel bar and while machining dynamometer is attached to lathe machine to measure the forces acting on the tool. Forces are measured in case of both textured and non-textured tool. Following graph between force and cutting speed shows the comparison of value of forces acting on both textured and non-textured tool at different speed.

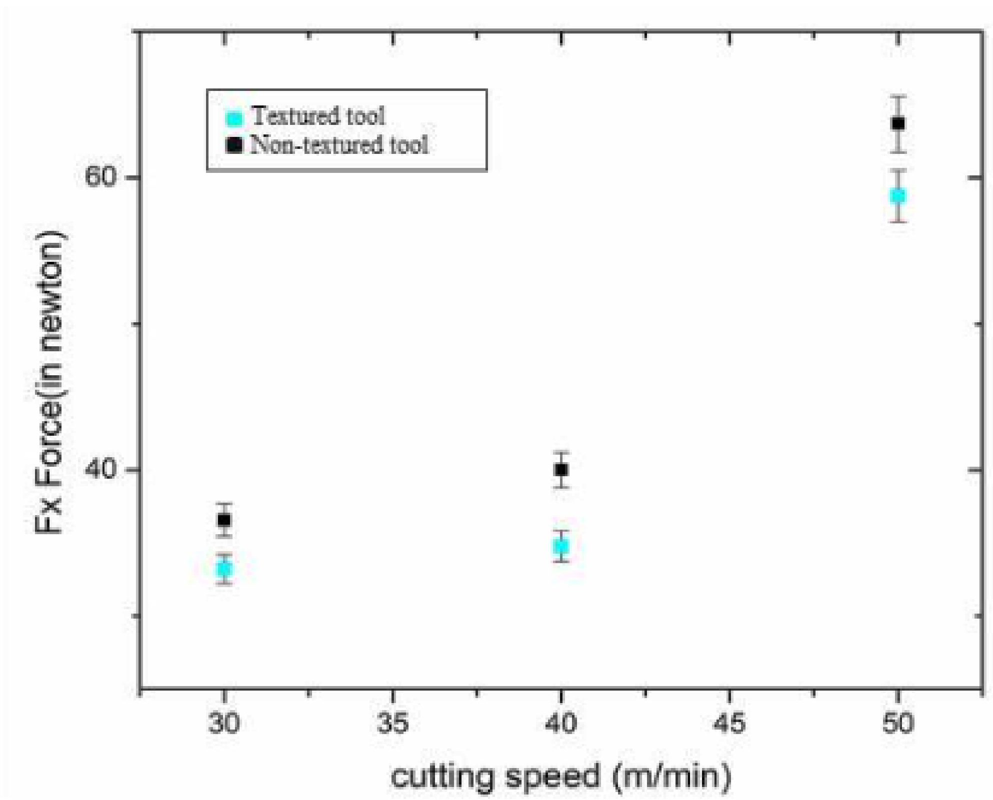


Figure35: Feed force vs cutting speed

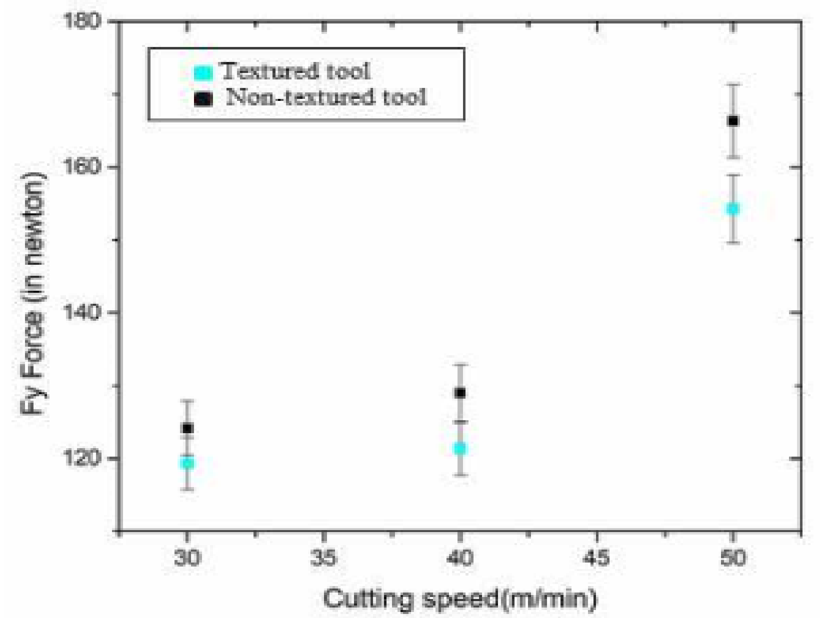


Figure36: Radial force vs cutting speed

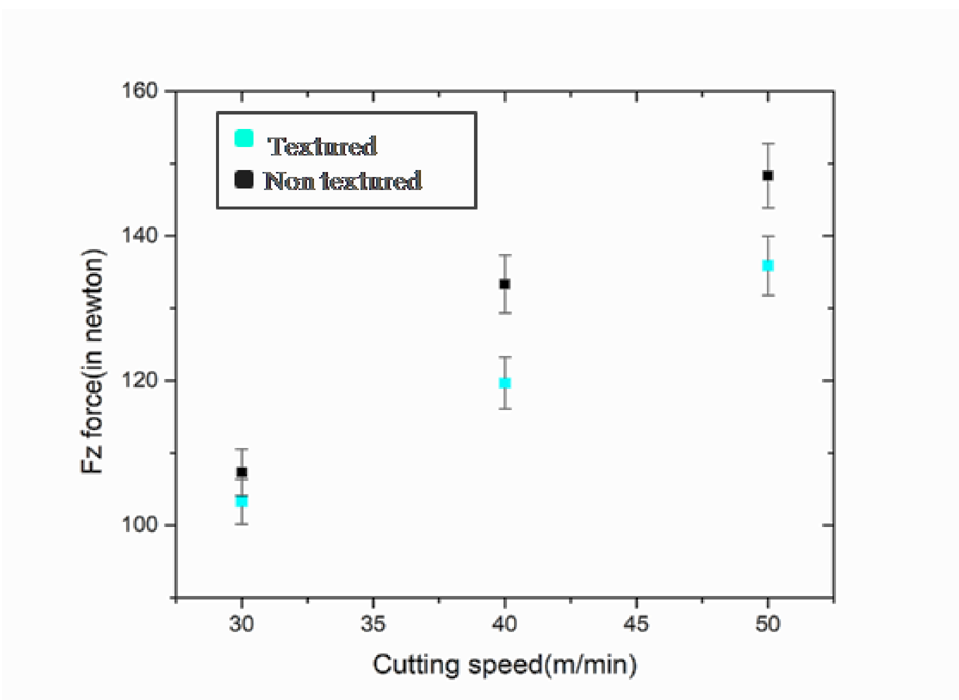


Figure 37: Cutting Force vs cutting speed

From above graph we can see the reduction in forces while using textured tool. Although reduction in forces is not that significant at lower cutting speed but in case of high cutting speed there is significant decrease in cutting force for textured tool.

Table 6: Forces acting in textured and non-textured tool at V=30 m/min, d=0.5mm, f=0.14mm/rev

	F_X	F_Y	F_Z
Non textured	31.56	124.16	120.34
Textured	29.77	119.33	116.63

Table 7: Forces acting in textured and non-textured tool at V= 40 m/min, d=0.5mm, f=0.14mm/rev

	F_X	F_Y	F_Z
Non textured	35.77	128.994	132.56
Textured	32.91	125.93	129.34

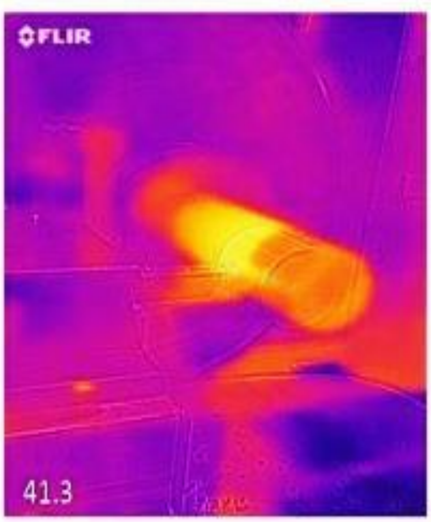
Table 8: Forces acting in textured and non-textured tool at V= 50 m/min, d=0.5mm, f=0.14mm/rev

	F_X	F_Y	F_Z
Non textured	39.65	134.53	143.76
Textured	37.33	131.67	135.33

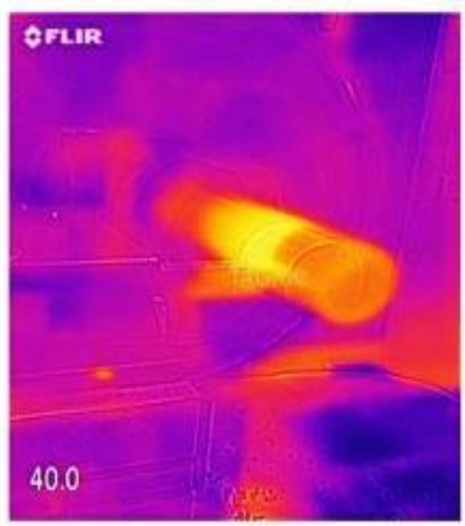
From table 5, 6 and 7 we can see the change in required force in case of textured and non-textured tool.

5.8 Effect of Texturing On Cutting Tool Temperature

In dry machining of mild steel rod, cutting edge temperature of tool was measured using thermal FLIR ONE camera. And it was observed that at higher speed, temperature of cutting edge of textured tool is less. The reason for reduction in cutting edge temperature is, the deposition acts as fin (as it provides more surface area for heat disposal) and hence maintains lower temperature as compare to tool without texturing. Apart from this the texturing reduces the contact length between tool and workpiece and this in turn reduces friction and hence heat generation also decreases. From figure we can see, at 30 m/min speed the reduction is 1.3 degree Celsius and at 40 m/min the reduction in tool temperature is about 3.3 degree Celsius whereas the decrease in tool temperature at 50 m/min is about 9.3 degree Celsius. The temperature of the tool keeps on varying during the machining operation and here we are comparing the temperature at the end of the turning operation.

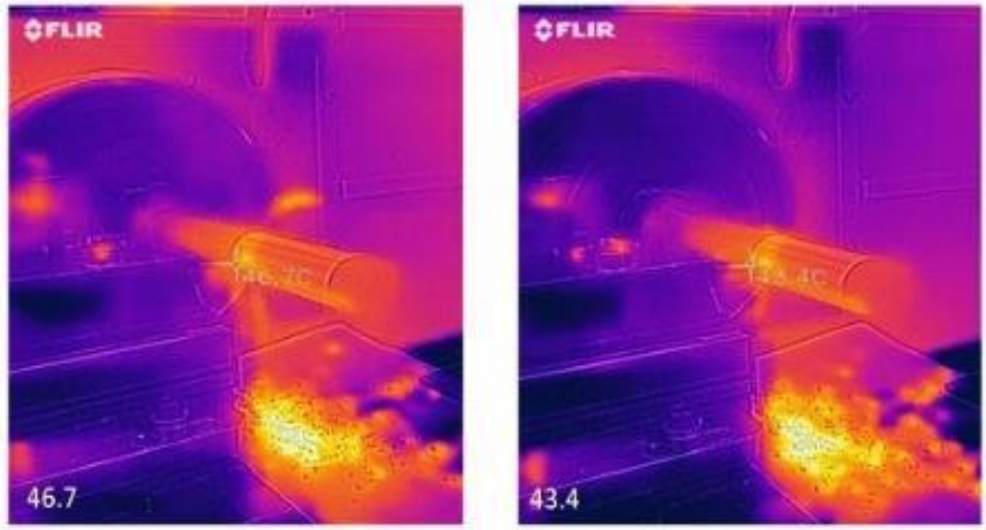


(A)Non-textured tool



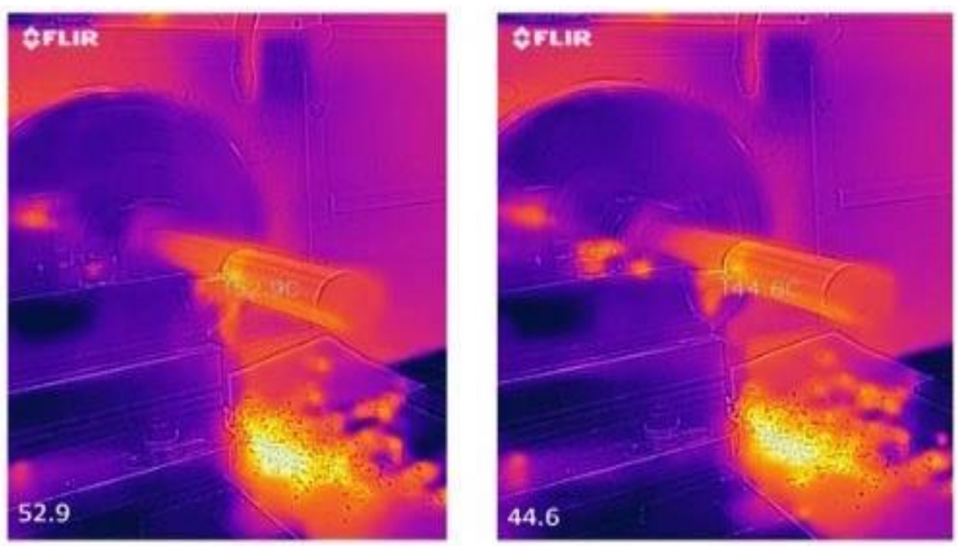
(B)Textured tool

Figure 38(a): Thermal images at V= 30 m/min, d=0.5mm, f=0.14mm/rev



(A)Non textured tool (B)Textured tool

Figure 38(b): Thermal images at V= 40 m/min, d=0.5mm, f=0.14mm/rev



(A)Non textured tool (B)Textured tool

Figure 38(c): Thermal images at V= 50 m/min, f=0.14 , d=0.5mm

From figure we can conclude that the rise in tool temperature while turning is less in case of textured tool while rise in temperature is more in non-textured tool. The texturing becomes more important in high speed machining for the reason being that as cutting speed increases temperature in chip-tool contact also increases and the heat generation at chip tool contact is major concern for tool life.

Summary - From this chapter we can conclude that Ni which is successfully deposited on the rack surface , acts as positive textures on the rack surface. Since the texturing process is carried out in open environment so some amount of Nickel oxide is also present in the textured part. From our investigations in turning operation on mild steel rod by textured and non-textured tool we find that there is reduction in chip size and required cutting force in case of textured tool and the temperature of the textured tool is also found to be less than that of non-textured tool during turning operation. Moreover effect of positive texturing is more significant at higher cutting speed as compare to lower cutting speed.

Chapter 6: Conclusion and Future scope

6.1: Conclusion

Following points can be concluded from this research work on investigation on effects of positive texturing of single point cutting tool using selective laser melting technique -

- Uniform melting of Nickel powder can be obtained at laser power of 50W .The extent of melting decreases as we decrease laser power .No melting is observed below power of 15 W irrespective of the change in other parameters i.e. scan speed ,number of passes.
- Optimized laser parameters for texturing of tool are –
  P =50W, scan speed =0.15 mm/sec, focal length=32cm, n=3.
- Use of textured tool in turning of mild steel rod has resulted in lesser value of cutting force, feed force and radial force as compare to non-textured tool.
- Smaller chips are formed in turning mild steel bar with textured tool as compare to non-textured cutting tool.
- The cutting tool temperature is found to be less in case of textured tool, for the reason being the texturing increases the surface area for heat dissipation from tool surface.
- At higher speed effect of texturing is more significant and chip size is less while machining with textured tool as compared to non-textured tool. There is 5 % to 6 % reduction in cutting force while using textured tool when compared to non-textured tool.

6.2: Future scope

This work comprises investigation on texturing of single point cutting tool using selective laser melting technique. Effects of texturing are analyzed in change in chip size, cutting force and cutting tool temperature in machining zone. So further some other suitable method can be used to deposit metal on tool surface, provided the adhesion between metal powder and tool should be strong enough to deflect the chip while machining, moreover positive texturing with different material can be tried provided the material should have higher melting point to sustain high temperature and good thermal conductivity to dispose off the heat from machining zone.

Chapter 7: References

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