EFFECT OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES OF ADDITIVE MANUFACTURING AL- ALLOY

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ABSTRACT: Additive manufacturing has become a highly researched topic in recent years all over the world. The 6061 series is a precipitation hardening alloy; containing magnesium and silicon (Si-Mg), 6061 aluminum is used extensively as a construction material, most commonly in the manufacture of automotive components and well-suited to the construction of motorcycles, bicycle frames, camera lenses, fishing reels, electrical fittings, & couplings, valves. In the present work investigation has been done to evaluate the effect of selective laser melting process parameters like (laser power, laser exposure time, spot size) on the microstructure and mechanical properties (Vickers hardness, wear resistance) of additive manufacturing Al-alloy was characterized. In the porosity of AlSi10 Mg in SLM done by various conditions altered the microstructure of all Specimens, Hardness is characterized by micro indentation on samples along building direction (along z-axis) and Wear resistance of frictional force values, and wear values of the specimens were plotted on graph according to the above mentioned working conditions. The obtained results demonstrate how these alter microstructure & hardness and wear resistance of additive manufacturing Al-alloy. AM has expanded over the last five years or so to include applications in many areas of our lives. From prototyping and tooling to direct part manufacturing in industrial sectors such as architectural, medical, dental, aerospace, furniture and jewellery, new and innovative applications are constantly being developed.

Key words: Al-alloy, SLM process, microstructure, mechanical properties.

1. INTRODUCTION

[1] In this study there are variants of suitable alloy systems depending on the percentage of scandium and magnesium applicable at the moment. Aluminum scandium master alloy (2 wt. % SC) was molten and magnesium, manganese, and zirconium were added. For the following investigation, the EOS M 270 machine was used. Influencing process parameters are 1stlaser related (laser power, spot size etc.), 2ND powder Related (particle shape, size, distribution, layer thickness etc.) and 3rd.scan related (scan speed, scan strategy, scan spacing) [10]. The Laser power of the EOS machine is limited to 200W, therefore it was set to 195W and a layer thickness of 20μm was chosen. To determine scan related, applicable parameters for an equally and non-porous consolidation of the welding paths, 20 test cubes were manufactured within one build sequence by variation of hatch distance and scan speed. The microstructure of each cube was evaluated by means of optical microscopy at various magnifications. After this initial study tensile test and Vickers hardness tests were done on one test cube in "as built up" condition and in "after artificial ageing" condition.[2] In this study AlSi10Mg powder this powder was also cross-sectioned and polished to investigate the presence of inherent pores using a microscope. The SLM process was conducted under an Argon atmosphere with an oxygen level below 0.5%. The test cubes produced were 5 mm × 5 mm × 5 mm. The study was divided into the three phases. There are hatch spacing, scan speed, scan orientation. Hatch spacing five sets of samples – each set comprising three samples – were produced using hatch spacing values of 50, 100, 150, 200, and 250m. The other parameters were kept constant for all samples in this batch (layer thickness = 40m, scanning speed = 500m/s, and 100 W laser power. 2. Scanning speed study the layer thickness and laser power were kept constant at 40m and 100 W, respectively. Scanning speed was varied between 250 and 1000 mm/s with 250 mm/s intervals, along with two different hatch spacing's (50 and 100m). 3. Scan orientation study the layer thickness was fixed at 40m for this study. The samples built were divided into three batches according to the scanning speed used (500, 750, and 1000 mm/s). [3] In this study in the present paper, the micro-structural evolution and mechanical properties of the DMLS-AlSi10Mg_200C alloy manufactured by recycled powder were investigated. There are several factors that significantly affect the quality of the SLM processing parameters (laser power, scan speed, hatch spacing, layer Thickness, bed temperature, etc.) The laser power, scanning speed, hatching distance and powder layer Thickness was 370 W, 1300 mm/s, 190μm and 30μm, respectively Samples used for cross-sectional Microstructure study, were polished using conventional metallographic methods to a 1μm finish and etched for 30 s using Keller's reagent. As the first step to characterize mechanical properties, hardness tests were carried out on the surfaces of the as-built cube samples and an average hardness value of 63 HRB was measured and is comparable to the hardness values reported for the as-built SLMAlSi10Mg parts manufactured by virgin powder. [4]In this study the objective of this work was to study the AA1050 characteristics, both in quasi-static and in dynamic conditions, with special focus on the material's hardness. This objective was achieved due to the fact that we were able to relate the Vickers Hardness of the material with some important properties like Stress, strain and strain rate. The relations achieved are experimental and very helpful in the prevision of the material behavior based on its Vickers Hardness. [5] In this study the additive manufactured test specimens were constructed using an aluminum alloy containing 10% silicon and 0.26% magnesium. The specimens were built on a 10-inch by 10-inch build platform. Each type of specimen was built in directions of 0°, 30°, 60°, and 90° relative to the build platform. Post-contour is used after the other passes along the edge of the specimen to improve surface Finish. [6] In this study the experimental investigations by preparing and testing of wear specimens consisting of LM 25 alloy reinforced with various proportions of nano-alumina and the wear rates were found. It is found that the reinforcement having a combination of 2.5 % addition of Nano-alumina shows better wear performances at both loading and unloading

conditions: The wear rate of the graded Nano-composite reinforced aluminum alloy material decreased with the increase of Nano-alumina in LM 25 aluminum alloy composition. The composition of 97.5%LM 25 + 2.5% Nano Al2O3 shows better wear performance comparing other compositions respectively. [7] In this it is unique equipment established to analyze frictional behavior and sliding wear properties of materials. The load applied to the pin can be up to 200 N. The wear track radius variation is from 10 to 65 mm. The disc speed can be varying from 200 to 2000 rpm. The sliding speed can be vary from 0.26 to 12m/s. LVDT (Linear Variable Displacement Transducer) and digital displacement monitor are used to measure the wear. [8]In this study the experimental investigation and the statistical optimization of the18Ni maraging 300steel parts built by the selective laser melting process. The experiments showed that parts with a relative density as high as99% can be built and that ρr% increases with the energy density. Parts with the relative density higher than 99% had a very low porosity that presented closed and regular shaped pores. [9] In this study the regression analysis method can be used to analyze the effect of SLM process parameters on the strut dimensions and mechanical properties of the lattice structures fabricated quantitatively. By careful manipulation of the process parameters, dimensional accuracy of the lattice structures can be improved. It can also lead to better control of the resulting mechanical properties.[10] In this study Furthermore, an extensive analysis of the available literature on the direct SLM of metals All the process and powder parameters reported above have been shown throughout the literature as having strong influences on the properties of metallic powdered parts fabricated via SLM with their effects being linked to what impact each has over the wetting conditions between the layers, density, surface roughness, dimensional accuracy, surface morphology, microstructure and mechanical properties. [11] In this study The response surface for porosity is a function of laser power (P), scan speed (v), hatch spacing (a1), and island size (Z) and can be expressed as follows the model coefficients that depend on the main and interaction effects of the process parameters. The ANOVA indicates that, within the investigated range of parameters, the porosity is mainly affected by laser power, scan speed and the interaction between the scan speed and hatch spacing. The response surface model prediction of porosity with respect to laser power and scan speed. It shows that decreasing the laser power and increasing the scan speed both results in an increased porosity. [12] In this study we report some results from a laboratory scale built semi continuous machine. Results show that regardless of the casting parameters used, a fine equated microstructure was obtained in every test.[13] In this study the relation of the processing parameters with tensile, bending strength, material flow & hardness of the joints were studied to attain defect free joints with proper mechanical strength, the hardness of the P after FSW decreased by the molecular weight reduction & AA5058 micro hardness increased because of the fine grinding after suffering thermo mechanical cycle.

[14] In this study the effect of changing scanning speed on the formation of single track, as well as the overlapping rate to form multi tracks during SLM processed Al-Cu-Mg alloy was investigated. A processing map for SLM single track of Al-Cu-Mg alloys was developed. Under different processing parameters, the single track can be characterized as unstable, stable with cracks and stable without cracks. [15] In this study friction stir processing (FSP) was performed on both age-hardened and non age-hardened Al alloys, with excellent damping properties obtained. The improved room temperature damping capacity of the FSP Al alloy can be mainly attributed to their low amount of solute atoms and the uniform distribution & high density of incoherent phases. [16] In this study to achieve that, the DSR-deformed samples were isochronally annealed for 1h at temp from 423k to 523 k with intervals of 25k.[17] In this study the as-cast dendritic structure was eliminated by heat treatment & subsequent rolling process resulting in improved mechanical properties. The strength & hardness increased with the increase in silver content up to 0.07wt% in combination with reasonable ductility. [18] In this study present work, the influence of Bi on the microstructures, tensile properties & fracture behavior of the cast Al-10Mg_2Si alloys has been systematically investigated. It was found that Bi addition caused a significant modification & refinement efficiency on the eutectic Mg_2Si in the Al-10Mg_2Si alloys.[19] In this study recrystallization occurred in the weld zones & recrystallization texture components were replaced by the shear texture components with increased rotation speeds. The development of shear texture precipitates dissolution &dislocations pinned by precipitates may result in the coarsening of the grains in the weld zones at higher rotation speeds. [20] In this study the mechanical properties of the FSP 7055 Al alloy were improved by the addition of Sc & pre-aging. The aged 7055-0.25Sc Al alloy with FSP showed the highest ultimate tensile strength of578 Mpa & the aged 7055 Al alloy with FSP showed the largest elongation of 21%. [21] In this study the aim of this bibliographical study is to identify & classify the parameters & phenomena which influence the appearance of defects in al alloy parts produced using the SLM process & the final properties of these parts for each defect or consequence identified porosities, defects linked with hot cracking phenomena, anisotropy in the surface quality & material. [22] In this study analyses the hardness response of different heat treatment temperatures & hold durations applied to a Sc & Zr modified Al-Mg (5***) alloy processed by SLM & compares the mechanical properties & microstructure in the as processed* annealed condition, & these properties are clearly related to the very fine grained microstructure. [23] In this study the high strength & ductility at very low mechanical anisotropy, which is a result of the alloys very fine-grained microstructure combined with weak texture in the build-up direction. [24] In this study SLM produced parts demonstrate slightly unfavorable corrosion resistance properties compared with their traditional counterparts. This work shows that, in addition to rapid manufacturing of parts, SLM can effectively refine the grains of eutectic Al12Si alloy. The SLM produced Al12Si shows an ultrafine-grained microstructure & improved corrosion resistance. [25] In this study although Al alloys are considered attractive material for this technology due to their high specific strength & favorable casting characteristics, their surface roughness may have a detrimental effect on their corrosion resistance & corrosion fatigue behavior in particular. [26] In this study the addition of 5wt% TiC improved the micro hardness of SLM produced Al15Si alloy, which had a remarkable micro hardness of 172.8HV. After the heat treatment (annealing or quenching), together with annealing treatment afterwards, was a feasible approach to obtain a high micro hardness & good wear resistance of Al15Si alloys .[27] In this study mechanical properties like tensile strength, elongation, Young's modulus, impact toughness and hardness are investigated for SLM-produced AlSi10Mg parts, and compared to conventionally cast AlSi10Mg parts. It is shown that AlSi10Mg parts with mechanical properties comparable or even exceeding to those of conventionally cast AlSi10Mg can be produced by SLM.

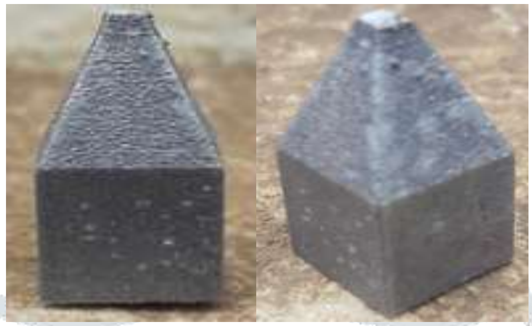
2. EXPERMENTAL

2.1 Materials:

Aluminum alloys are highly sought after because they are lightweight and have excellent corrosion resistance. Pure aluminum does not possess great mechanical properties unless it is alloyed with other metals. In order to reach the higher strengths required for different applications. These metal additions also help produce alloys with varying ductility. The alloys include a lower initial cost and the ability to make cube shapes. The alloy also has good corrosion resistance, machinability, and toughness. The 6061 Aluminum alloy consists of 0.8-1.2% Mg, and 0.4-0.8% Si. The density of 6061 aluminum alloy is 2.7 g/cm3. Applications for 6061 aluminum alloy include construction materials, aircraft and automotive components, beverage containers, and structural pipes.

2.2 Processing:

The additive manufactured test specimens were constructed using an aluminum alloy containing 0.8-1.2% magnesium, and 0.4-0.8% silicon. The specimens were built on a 10*10 mm by cube shaped. Which can be seen in Figure shows the specimens used for the Vickers hardness test and wear properties (pin on disc), microstructure and selective laser melting process.



Aluminum alloy containing (0.8-1.2% magnesium, and 0.4-0.8% silicon)

2.3 Electrical discharge machining:

In the above figure cutting in a two parts by the using on wire electrical discharge machining (WEDM), also known as wire-cut EDM and wire cutting, a thin single-stand metal wire usually brass is fed through the work piece, submerged in a tank of dielectric fluid, typically de-ionized water.

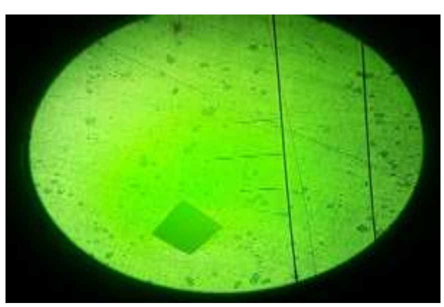
After cutting in EDM machine

2.4 Process Parameters in SLM:

In additive manufacturing technology, many parameters influence the correctness of SLM process. By proper analysis of those parameters, one can understand the occurring mechanisms in an appropriate way to design the process. SLM is a complex process where a large number of parameters can influence the quality of the final part. In SLM, the main process parameters are laser power, laser exposure time, spot size, and hatch spacing, layer thickness are used.

2.5Vickers Hardness Test:

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a test force of 1 kg. The full load is normally applied for 10 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surfaces of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kg load by the square mm area of indentation.



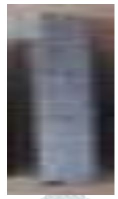
After force applied on the aluminum alloy as a diamond indentation

2.6 Micro-structural Analysis:

The microstructures of mechanically tested aluminum 16 samples were analyzed to determine the effects of additive manufacturing had on grain structure. The mounted samples were successively polished using 320, 400, 600, 800, 1000 and 1200 grit sandpaper followed by final 5 µm and 1 µm alumina slurry on a felt polisher and after polished samples were etched. Micro-structural pictures were taken at 50 µm 100 µm, 200 µm magnifications using the microscope

2.7 Pin on disc wear test:

Sliding wear tests were conducted in pin-on-disc wear testing properties loaded condition of 0.5kg, 1kg and 1.5kg at a fixed sliding speed of 640 rpm and steel disc for a track diameter 120mm and time 5 minutes. The pins used in this research were produced with a diameter of 4 mm and height of 2 cm. The Disk used in this research was made of steel. The surface of steel disc is cleaned and washed by ethanol.



Wear specimen of aluminum alloy

Pin on disc wear testing setup:

The surfaces of the pin sample are made as cube shape without any minor fins using emery paper prior to the test in order to ensure effective contact with the steel disc. During sliding, the load is applied to the specimen through cantilever mechanism and the specimens brought in intimate contact with the rotating disc during loading condition at a track radius of 120 mm. The pin is made to slide against the steel disc for about five minutes at dry lubrication conditions. The corresponding wear of the pin against the time is plotted graphically. During the cantilever assembly which holds the specimen is connected to a weight holder in which can carry a maximum of 5 kg load. After the proper loading condition the specimen is allowed to slide at specific speed 640 rpm setup. From the graph it is evident that the values of wear for the particular composition can be attained in micrometers.

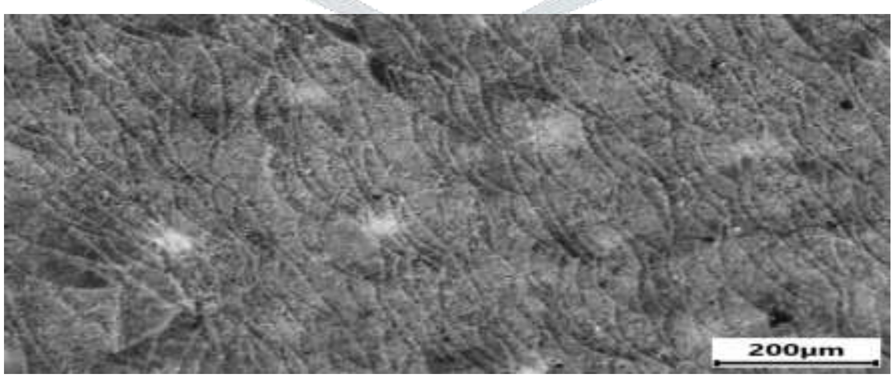
RESULTS:

→Sample 1:
SLM PROCESS:
Layer thickness 30 Microns
Hatch Distance 50 Microns
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
1	100	120	70

→ HARDNESS:
Sample 1: 30.634 HV

→ POROSITY:

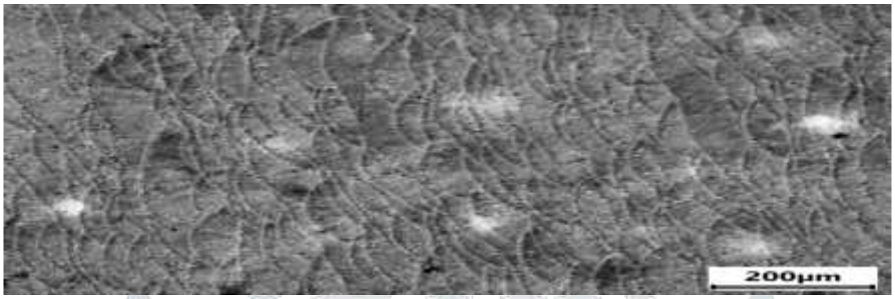


In the 1st sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 100w, laser exposure time 120 µs and spot size 70 µm are used. And process parameters are used in hardness by micro indentation process value is 30.634HV, these process parameters to use in porosity on microstructure.

→ Sample 2:
SLM PROCESS:
Layer thickness 30 Microns
Hatch Distance 50 Microns
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
2	100	130	70

→ HARDNESS:
Sample 2: 31.708 HV
→ POROSITY:

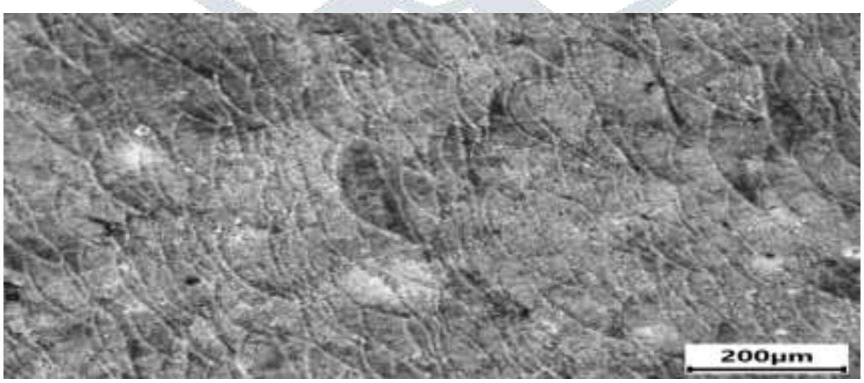


In the 2nd sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 100w, laser exposure time 130µs and spot size 70µm are used. And process parameters are used in hardness by micro indentation process value is 31.708HV, these process parameters to use in porosity on microstructure.

→ Sample 3:
SLM PROCESS:
Layer thickness 30 Microns
Hatch Distance 50 Microns
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
3	100	140	70

→ HARDNESS:
Sample 3: 29.918 HV
→POROSITY:



In the 3rd sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 100w, laser exposure time 140µs and spot size 70µm are used. And process parameters are used in hardness by micro indentation process value is 29.918HV, these process parameters to use in porosity on microstructure.

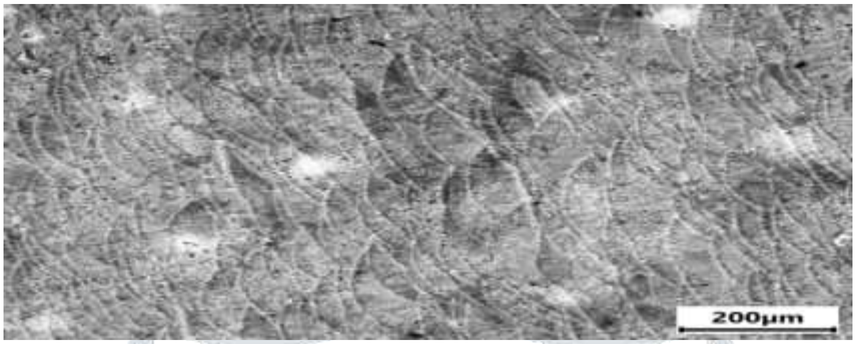
→Sample 4:
SLM PROCESS:
Layer thickness 30 Microns
Hatch Distance 50 Microns
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
4	100	150	70

→ HARDNESS:

Sample 4: 31.874 HV

→POROSITY:



In the 4th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 100w, laser exposure time 150 µs and spot size 70µm are used. And process parameters are used in hardness by micro indentation process value is 31.874HV, these process parameters to use in porosity on microstructure.

→Sample 6:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

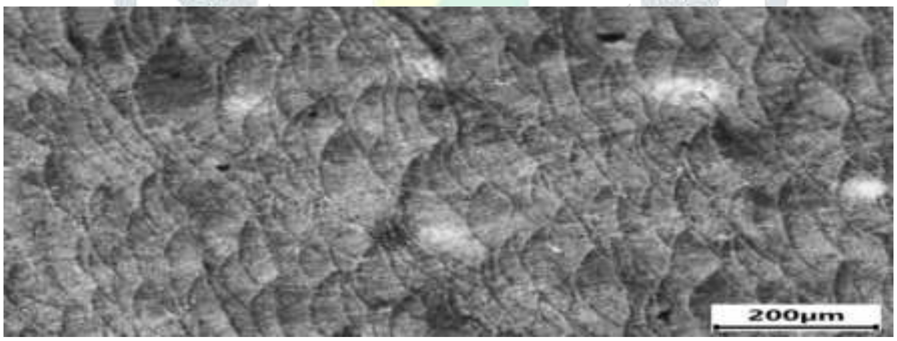
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
6	125	120	80

→ HARDNESS:

Sample 6: 31.244 HV

→POROSITY:



In the 6th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 125w, laser exposure time 120 µs and spot size 80µm are used. And process parameters are used in hardness by micro indentation process value is 31.244HV, these process parameters to use in porosity on microstructure.

→Sample 7:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

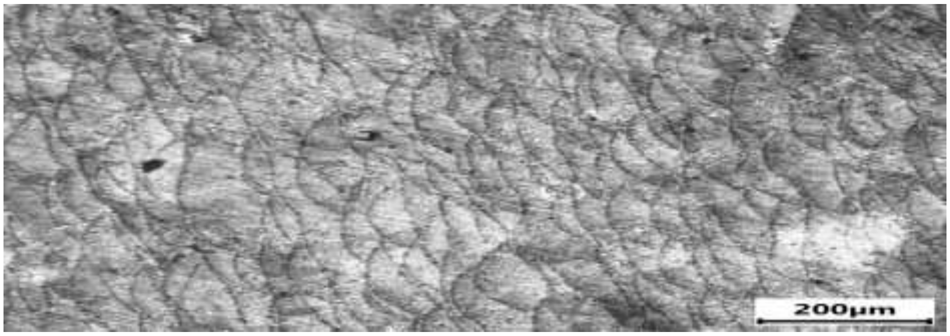
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
7	125	130	80

→ HARDNESS:

Sample 7: 30.89 HV

→POROSITY:



In the 7th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 125w, laser exposure time 130 µs and spot size 80µm are used. And process parameters are used in hardness by micro indentation process value is 30.89HV, these process parameters to use in porosity on microstructure.

→Sample 8:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

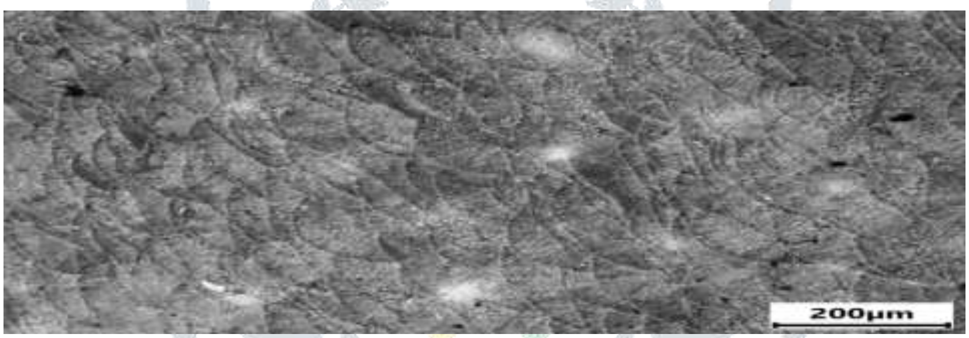
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
8	125	140	80

→ HARDNESS:

Sample 8: 33.21 HV

→POROSITY:



In the 8th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 125w, laser exposure time 140 µs and spot size 80µm are used. And process parameters are used in hardness by micro indentation process value is 33.21HV, these process parameters to use in porosity on microstructure.

→Sample 9:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

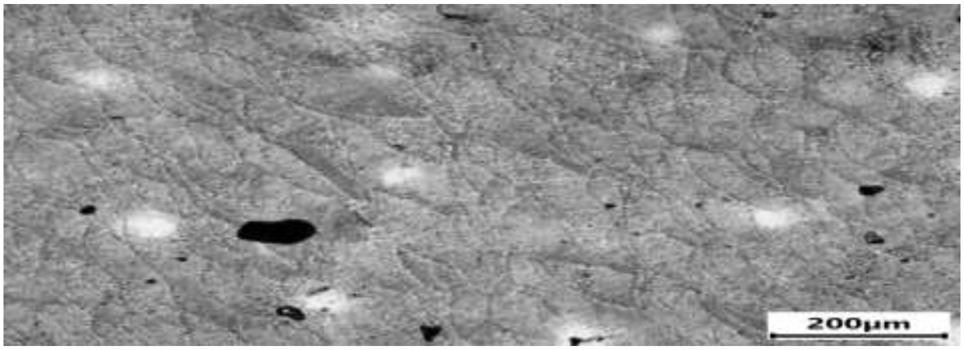
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
9	125	150	80

→ HARDNESS:

Sample 9: 30.606 HV

→POROSITY:



In the 9th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 125w, laser exposure time 150 µs and spot size 80µm are used. And process parameters are used in hardness by micro indentation process value is 30.606HV, these process parameters to use in porosity on microstructure.

→Sample 11:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

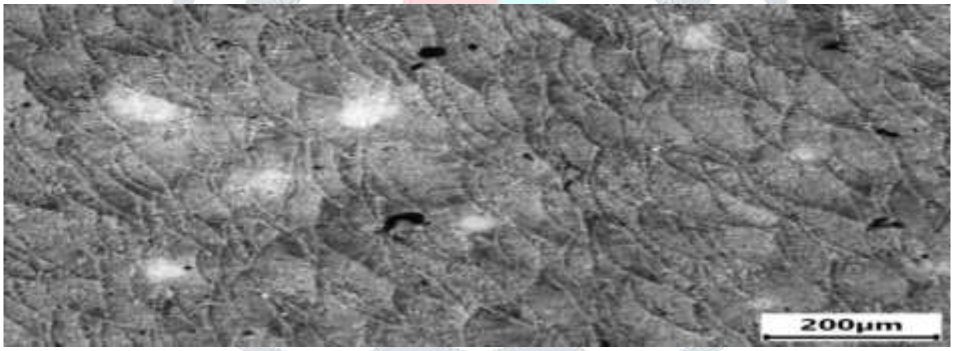
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
11	125	120	90

→ HARDNESS:

Sample 11: 30.038 HV

→ POROSITY:



In the 11th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 125w, laser exposure time 120 µs and spot size 90µm are used. And process parameters are used in hardness by micro indentation process value is 30.038HV, these process parameters to use in porosity on microstructure.

→Sample 12:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

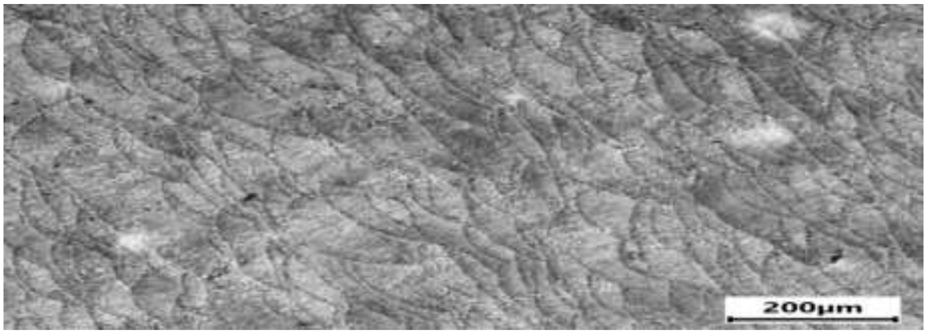
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
12	150	130	90

→ HARDNESS:

Sample 12: 31.14 HV

→POROSITY:



In the 12th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 150w, laser exposure time 130 µs and spot size 90µm are used. And process parameters are used in hardness by micro indentation process value is 31.14HV, these process parameters to use in porosity on microstructure.

→Sample 13:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

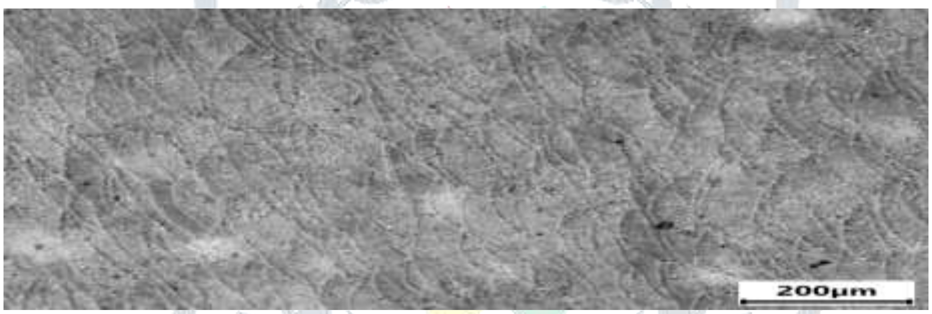
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
13	150	140	90

→ HARDNESS:

Sample 13: 29.73 HV

→POROSITY:



In the 13th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 150w, laser exposure time 140 µs and spot size 90µm are used. And process parameters are used in hardness by micro indentation process value is 29.73HV, these process parameters to use in porosity on microstructure.

→ Sample 14:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

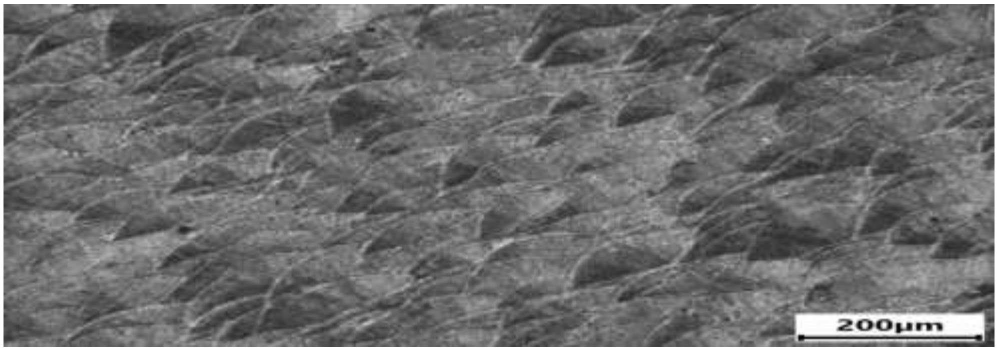
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
14	150	150	90

→ HARDNESS:

Sample 14: 29.98 HV

→POROSITY:

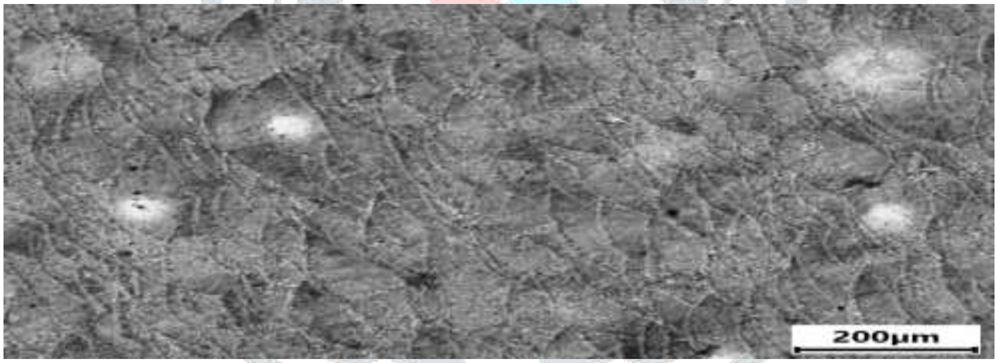


In the 14th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30μ and 50μ respectively. And laser power 150w, laser exposure time 150 μs and spot size 90μm are used. And process parameters are used in hardness by micro indentation process value is 29.98HV, these process parameters to use in porosity on microstructure.

→Sample 16:
SLM PROCESS:
Layer thickness 30 Microns
Hatch Distance 50 Microns
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
16	175	120	100

→ HARDNESS:
Sample 16: 28.45 HV
→POROSITY:

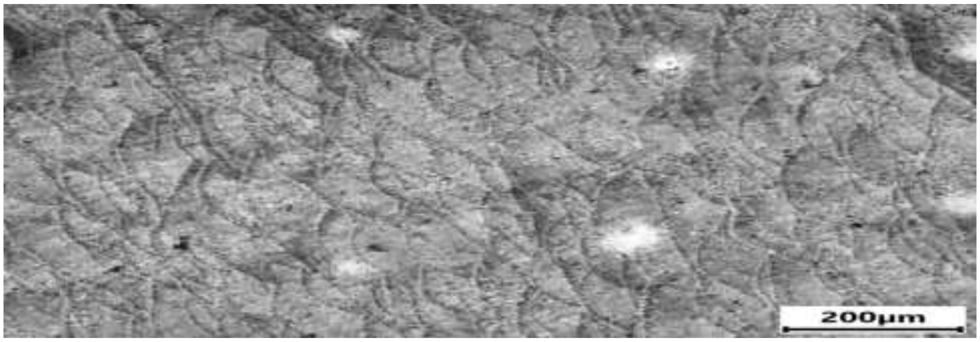


In the 16th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30μ and 50μ respectively. And laser power 175w, laser exposure time 120 μs and spot size 100μm are used. And process parameters are used in hardness by micro indentation process value is 28.45HV, these process parameters to use in porosity on microstructure.
→Sample 17:
SLM PROCESS:
Layer thickness 30 Microns
Hatch Distance 50 Microns
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
17	175	130	100

→ HARDNESS:
Sample 17: 29.87 HV

→POROSITY:



In the 17th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30μ and 50μ respectively. And laser power 175w, laser exposure time 130 μs and spot size 100μm are used. And process parameters are used in hardness by micro indentation process value is 29.87HV, these process parameters to use in porosity on microstructure.

→Sample 18:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

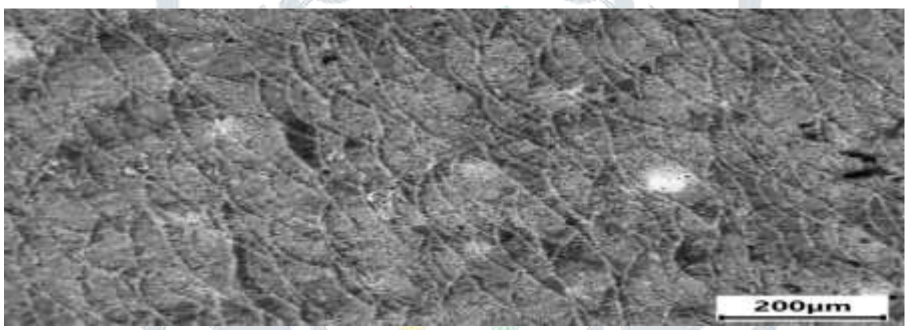
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
18	175	140	100

→ HARDNESS:

Sample 18: 30.15 HV

→POROSITY:



In the 18th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30μ and 50μ respectively. And laser power 175w, laser exposure time 140 μs and spot size 100μm are used. And process parameters are used in hardness by micro indentation process value is 30.15HV, these process parameters to use in porosity on microstructure.

→ Sample 19:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

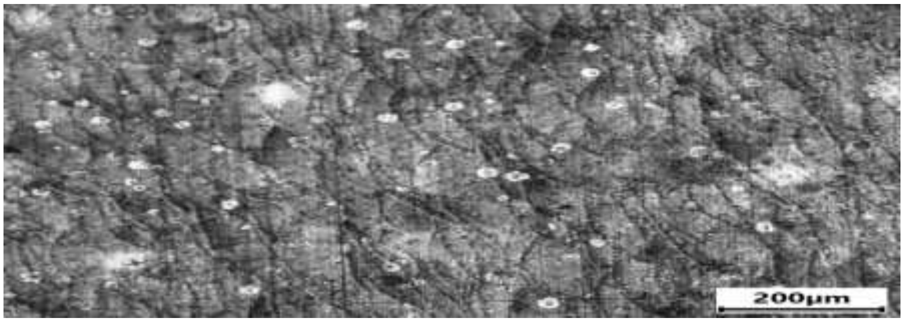
Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
19	175	150	100

→ HARDNESS:

Sample 19: 30.24 HV

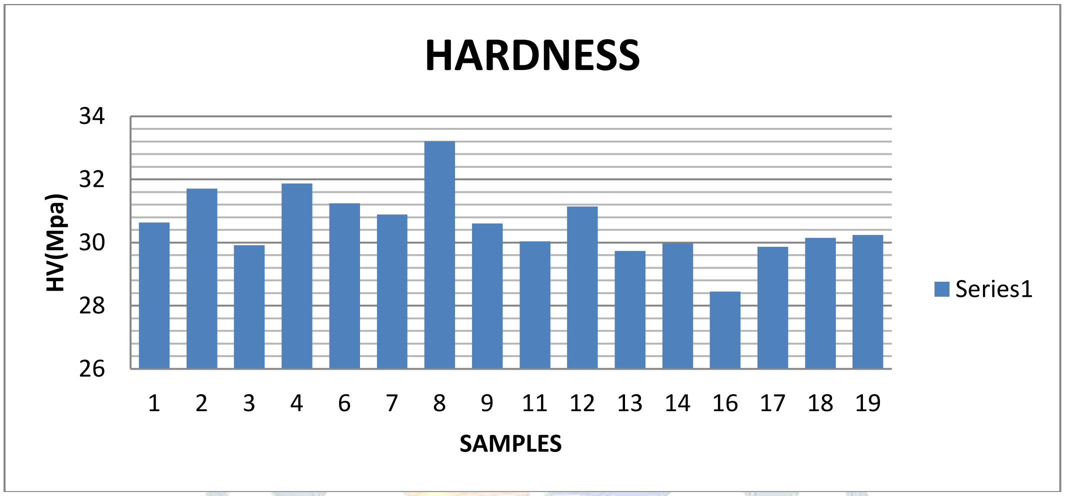
→POROSITY:



In the 19th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 175w, laser exposure time 150 µs and spot size 100µm are used. And process parameters are used in hardness by micro indentation process value is 30.24HV, these process parameters to use in porosity on microstructure.

HARDNESS GRAPH:

LAYER BY LAYER PROCESS AVERAGE VALUES GRAPH:



WEAR RESISTANCE:

→ Sample 5:

SLM PROCESS:

Layer thickness 30 Microns

Hatch Distance 50 Microns

Scanning Strategy is Meander

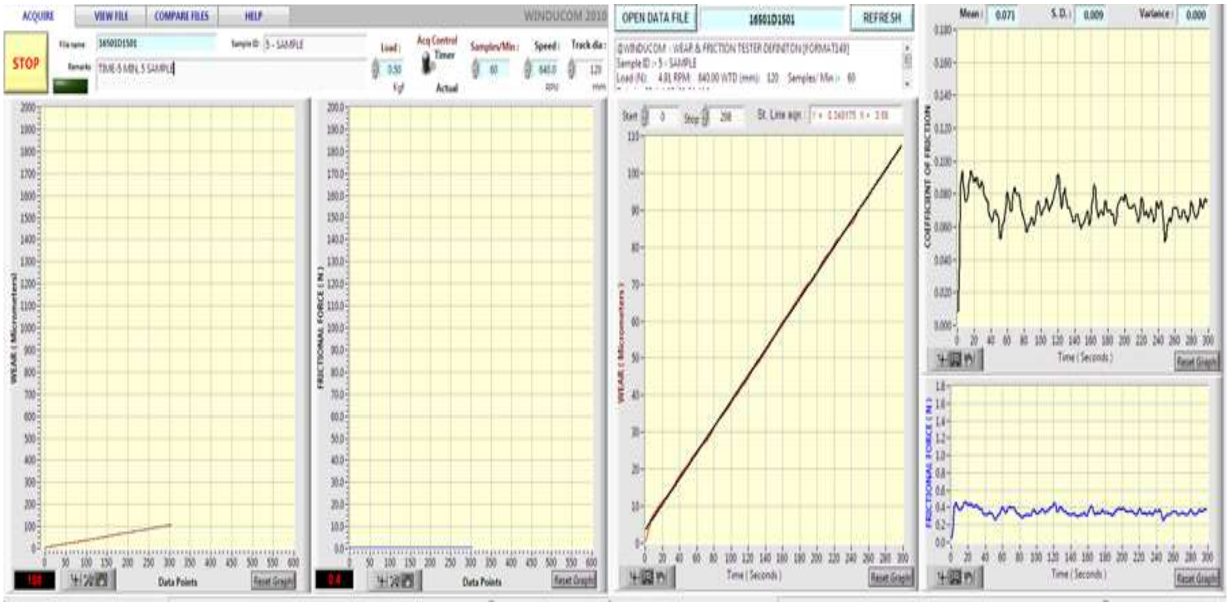
Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
5	100	160	70

Wear properties:

Sample 5 :

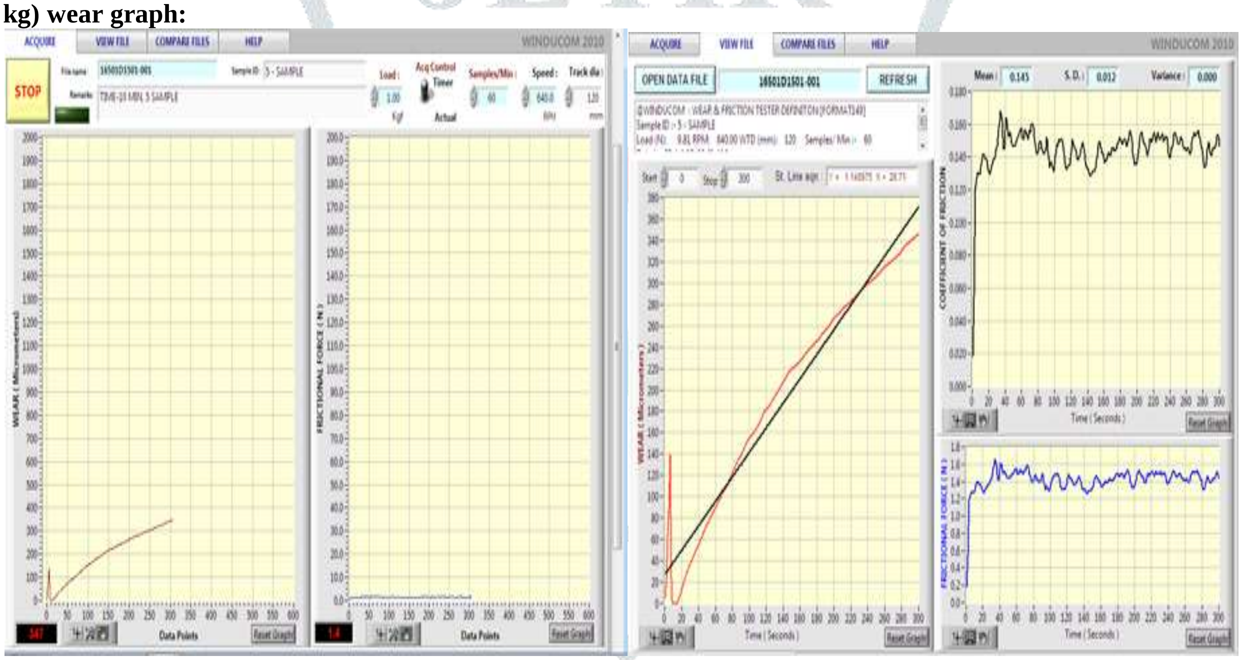
WEIGHT (kg)	TIME (min)	SPEED (rpm)	TRACK DIAMETER (mm)	WEAR (microns)	FRICTIONAL PROCESS (Newton's)
0.5	5	640	120	108	0.4
1	5	640	120	347	1.4
1.5	5	640	120	324	1.0

5th sample (0.5kg) wear graph:



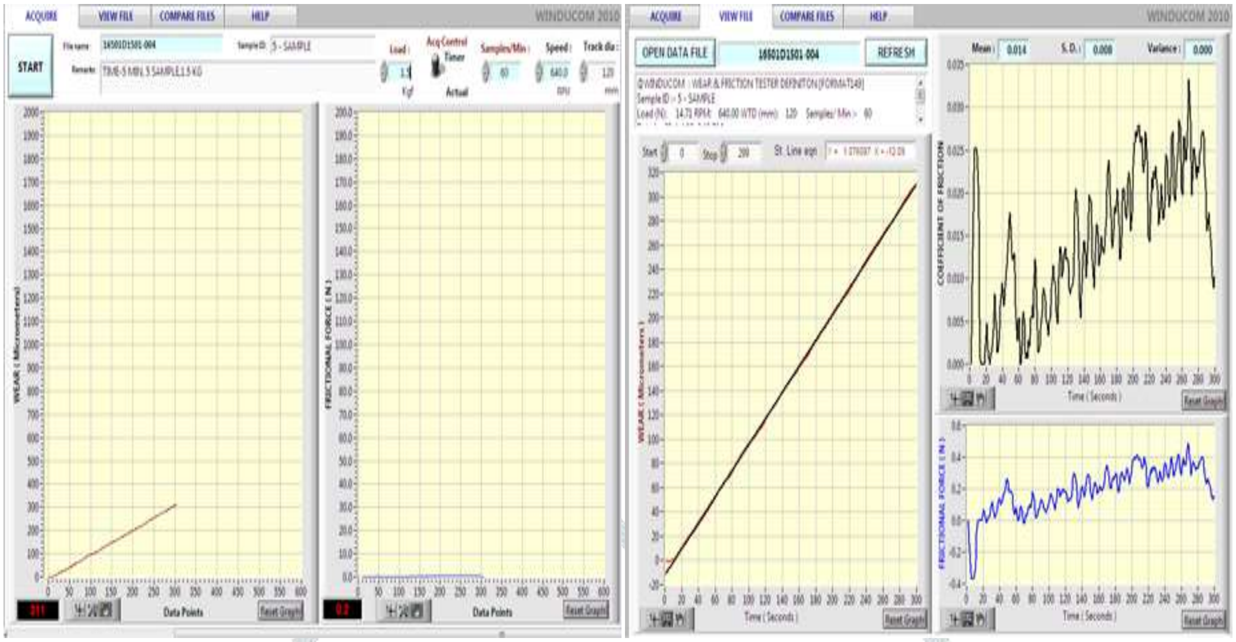
In the 5th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30 µ and 50 µ respectively. And laser power 100w, laser exposure time 160µs and spot size 70µm are used. This process parameters used in wears resistance as a graph showed the wear Behavior at 0.5 kg load. It wears loss of 108µm and frictional force 0.4 Newton.

5th sample (1 kg) wear graph:



In the 5th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30 µ and 50 µ respectively. And laser power 100w, laser exposure time 160µs and spot size 70 µm are used. This process parameters used in wears resistance as a graph showed the wear Behavior increased at 1 kg load. It wears loss of 347µm and frictional force 1.4newton.

5th sample (1.5kg) wear graph:



In the 5th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30 µ and 50 µ respectively. And laser power 100w, laser exposure time 160µs and spot size 70 µm are used. This process parameters used in wears resistance as a graph showed the wear Behavior increased at 1.5 kg load. It wears loss of 311µm and frictional force 0.2newton.

5th sample comparssion graph :

In the 5th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30 µ and 50 µ respectively. And laser power 100w, laser exposure time 160µs and spot size 70µm are used. And wear properties graph showed the wear Behavior of 5th sample at 0.5 kg & 1 kg & 1.5 kg load applied. It wears loss of a maximum of 1 kg load 347µm and frictional force 1.0 Newton.

→Sample 10:

SLM process:

Layer thickness 30 Microns

Hatch Distance 50 Microns, Scanning Strategy is Meander

Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
10	125	160	80

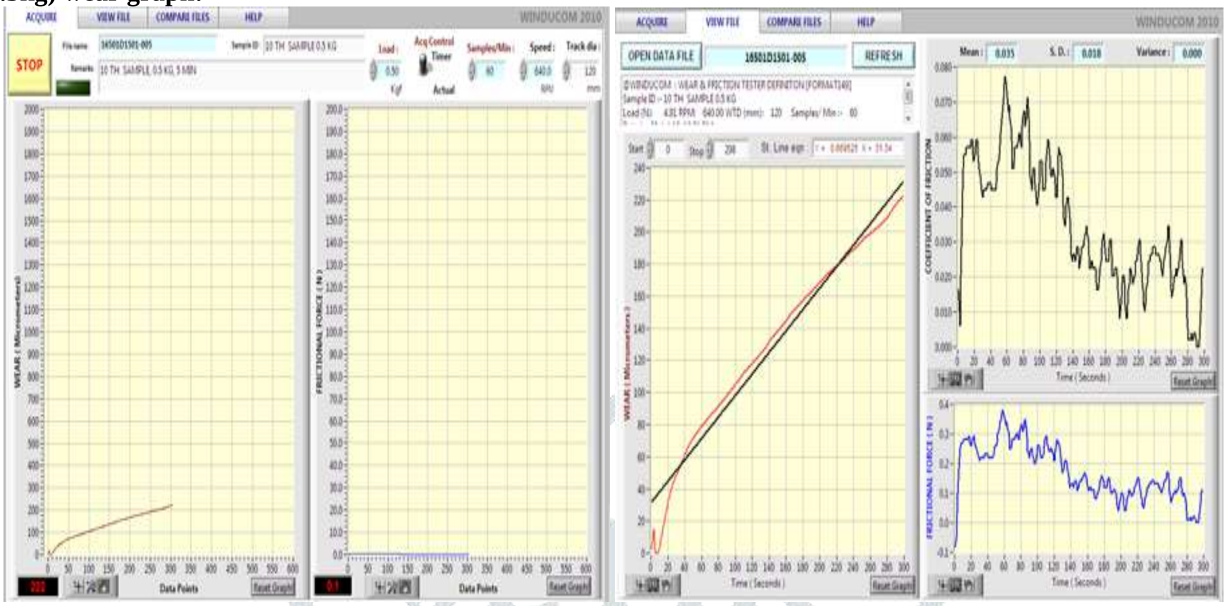
Wear properties:

Sample 10 :

WEIGHT (kg)	TIME (min)	SPEED (rpm)	TRACK DIAMETER (mm)	WEAR (microns)	FRICTIONAL PROCESS (Newton's)
0.5	5	640	120	222	0.1

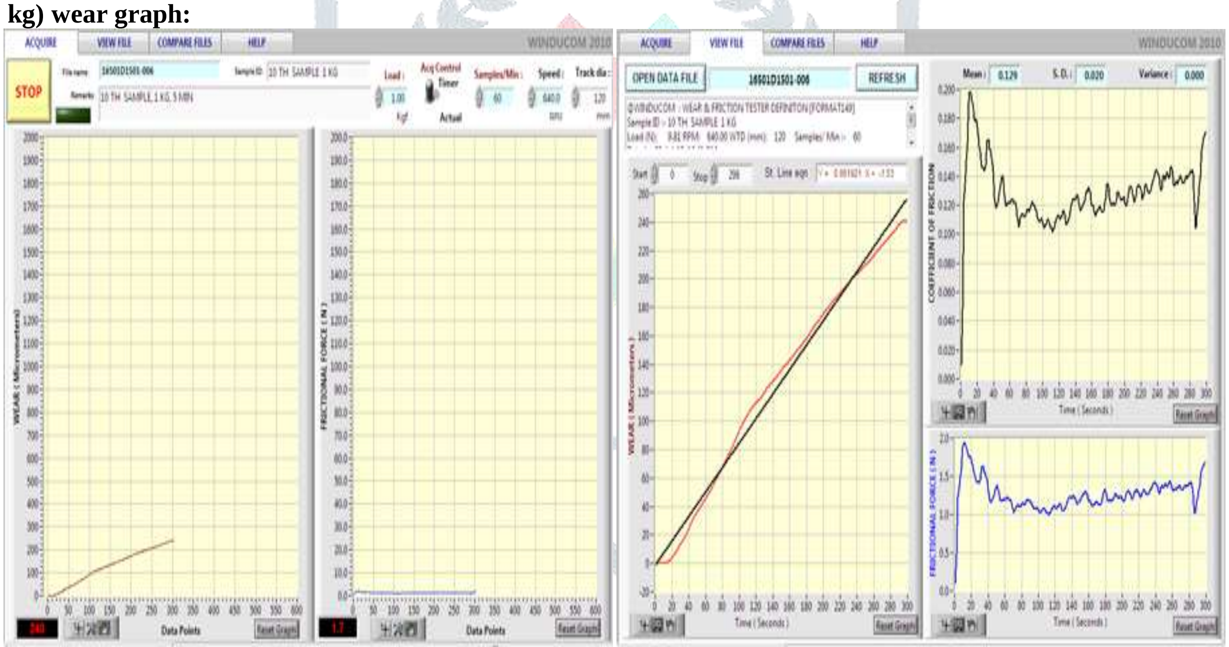
1	5	640	120	240	1.7
1.5	5	640	120	556	1.2

10th sample (0.5kg) wear graph:



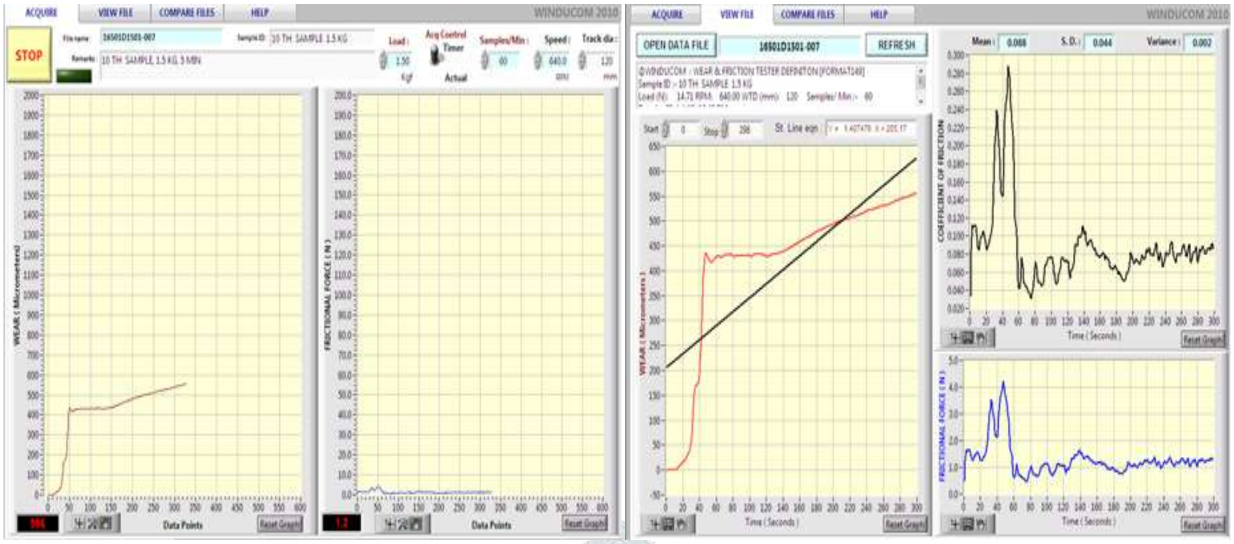
In the 10th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30 µ and 50 µ respectively. And laser power 125w, laser exposure time 160µs and spot size 80 µm are used. This process parameters used in wears resistance as a graph showed the wear Behavior increased at 0.5 kg load. It wears loss of 222µm and frictional force 0.1newton.

10th sample (1 kg) wear graph:



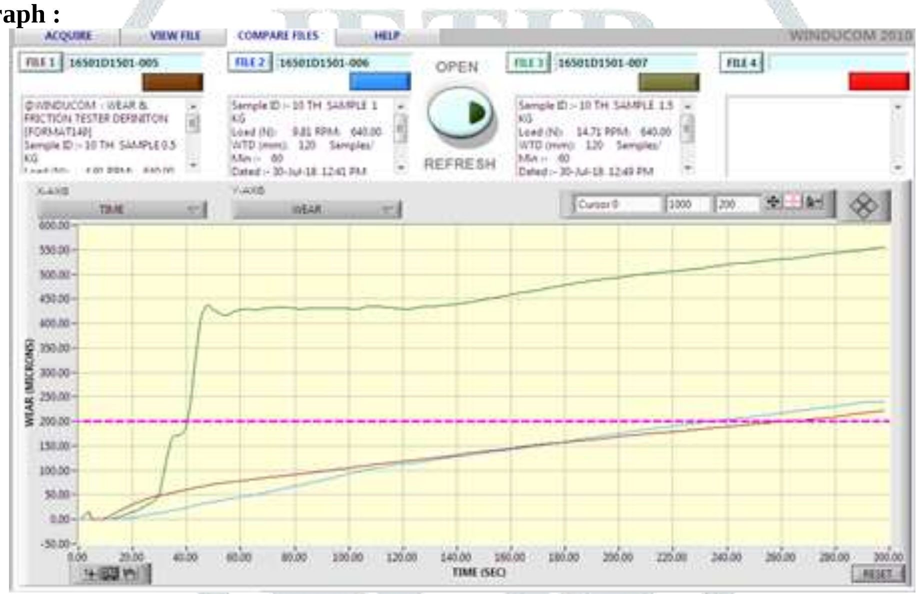
In the 10th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 125w, laser exposure time 160µs and spot size 80µm are used. This process parameters used in wears resistance as a graph showed the wear Behavior increased at 1 kg load. It wears loss of 240µm and frictional force 1.7newton.

10th sample (1.5kg) wear graph:



In the 10th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 125w, laser exposure time 160µs and spot size 80µm are used. This process parameters used in wears resistance as a graph showed the wear Behavior increased at 1.5 kg load. It wears loss of 556µm and frictional force 1.2newton.

10th sample comparssion graph :



In the 10th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30µ and 50µ respectively. And laser power 125w, laser exposure time 160µs and spot size 80µm are used. And wear properties graph showed the wear Behavior of 10th sample at 0.5 kg & 1 kg & 1.5 kg load applied. It wears loss of a maximum of 1.5 kg load 556µm and frictional force 1.2 Newton.

→ Sample 15:

SLM process:
Layer thickness 30 Microns
Hatch Distance 50 Microns
Scanning Strategy is Meander

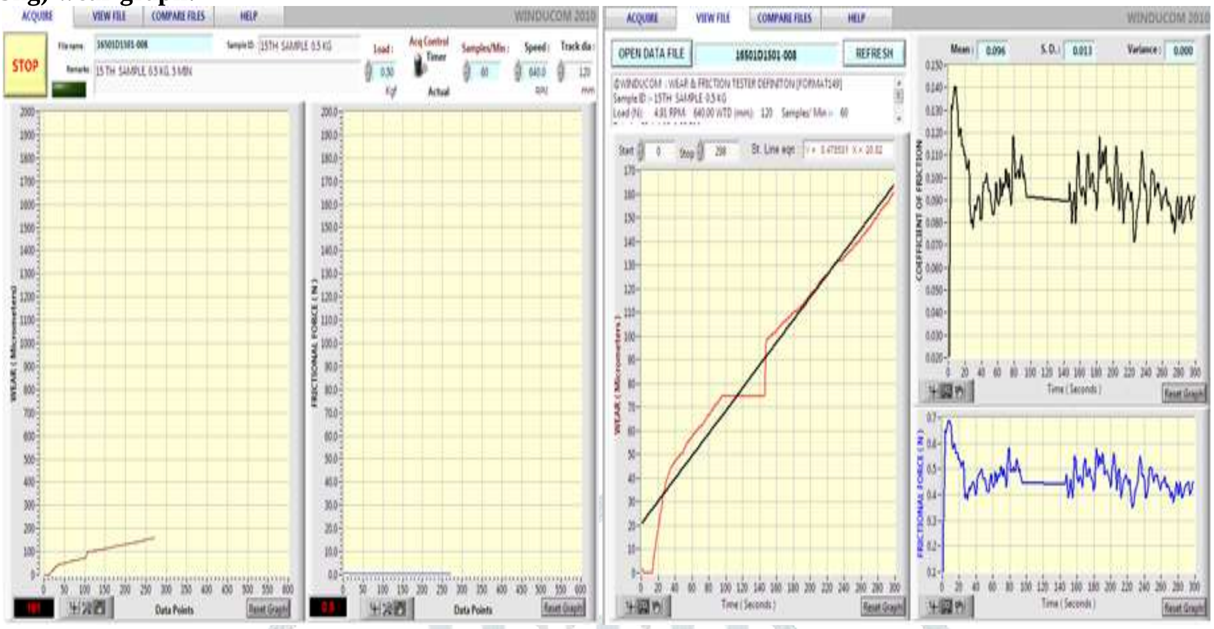
Sample Number	Laser Power(Watts)	Laser Exposure Time (Micro Seconds)	Point Distance (Micro Meter)
15	150	160	90

Wear properties:

Sample 15 :

WEIGHT (kg)	TIME (min)	SPEED (rpm)	TRACK DIAMETER (mm)	WEAR (microns)	FRICTIONAL PROCESS (Newton's)
0.5	5	640	120	161	0.5
1	5	640	120	789	0.9
1.5	5	640	120	239	2.4

15th sample (0.5kg) wear graph:

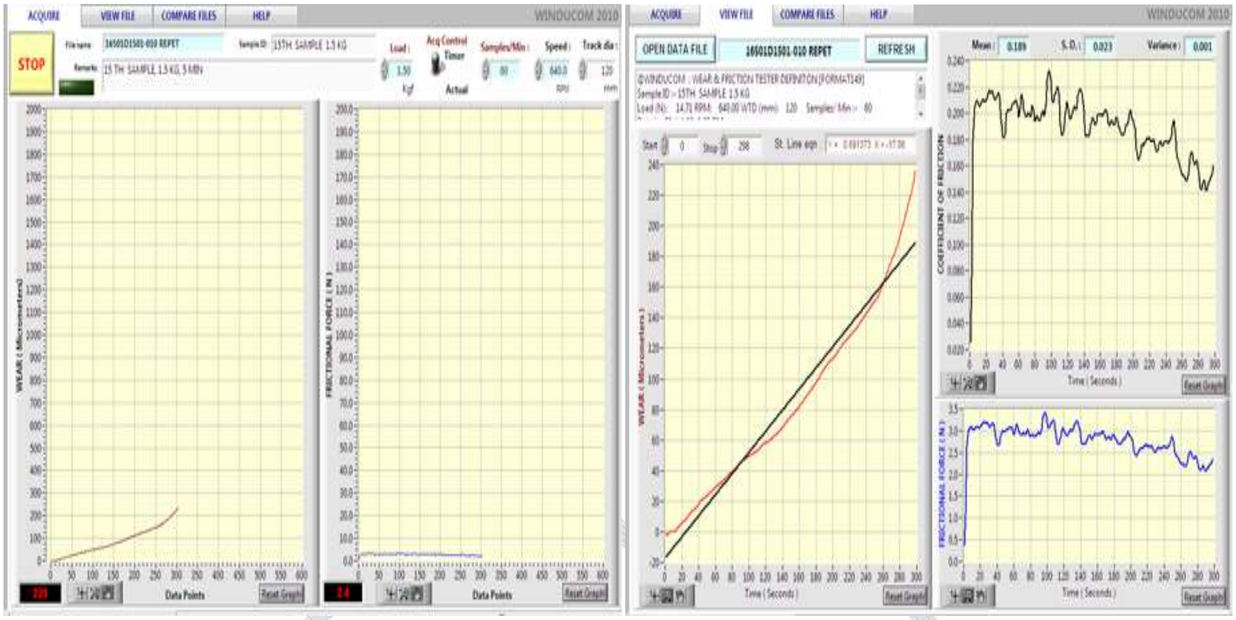


In the 15th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30 µ and 50 µ respectively. And laser power 150w, laser exposure time 160µs and spot size 90µm are used. This process parameters used in wears resistance as a graph showed the wear Behavior increased at 0.5 kg load. It wears loss of 161µm and frictional force 0.5newton.

15th sample (1 kg) wear graph:

In the 15th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30 µ and 50 µ respectively. And laser power 150w, laser exposure time 160µs and spot size 90µm are used. This process parameters used in wears resistance as a graph showed the wear Behavior increased at 1 kg load. It wears loss of 789 µm and frictional force 0.9newton.

15th sample (1.5kg) wear graph:



In the 15th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30 µ and 50 µ respectively. And laser power 150w, laser exposure time 160µs and point distance 90µm are used. This process parameters used in wears resistance as a graph showed the wear Behavior increased at 1.5 kg load. It wears loss of 239 µm and frictional force 2.4newton.

15th sample comparssion graph :

In the 15th sample SLM process parameters are used in layer thickness and Hatch Distance were kept constant at 30 µ and 50 µ respectively. And laser power 150w, laser exposure time 160µs and point distance 90µm are used. And wear properties graph showed the wear Behavior of 10th sample at 0.5 kg & 1 kg & 1.5 kg load applied. It wears loss of a maximum of 1 kg load 789 µm and frictional force 0.9 Newton.

CONCLUSSION

In the work investigation has been done to the effect of selective laser melting process parameters like (laser power, laser exposure time, spot size) on the microstructure and mechanical properties (Vickers hardness, wear resistance) of additive manufacturing Al-alloy was characterized.

Where process parameters of

LT = layer thickness (microns) HD = hatch distance (microns)

LP = laser power (watts) SS= spot size (micro meter)

LET= laser exposure time (micro seconds)

Table.1

SAMPLE NUMBER	PROCESS PARAMETER	HARD NESS	POROSITY	WEAR PROPERTIES
1	LT 30 µ, HD 50 µ, LP 100 w, LET 120 µs,	30.634 HV	385.26	–

	SS 70 µm.			
2	LT 30 µ, HD 50 µ, LP 100 w, LET 130 µs, SS 70 µm.	31.708 HV	258.96	–
3	LT 30 µ, HD 50 µ, LP 100 w, LET 140 µs, SS 70 µm.	29.918 HV	395.23	–
4	LT 30 µ, HD 50 µ, LP 100 w, LET 150 µs, SS 70 µm.	31.874 HV	239.03	–
6	LT 30 µ, HD 50 µ, LP 125 w, LET 120 µs, SS 80 µm.	31.244 HV	354.03	–
7	LT 30 µ, HD 50 µ, LP 125 w, LET 130 µs, SS 80 µm.	30.89 HV	365.51	–
8	LT 30 µ, HD 50 µ, LP 100 w, LET 140 µs, SS 70 µm.	33.21 HV	265.16	–
9	LT 30 µ, HD 50 µ, LP 125 w, LET 150 µs, SS 80 µm.	30.606 HV	756.17	–
11	LT 30 µ, HD 50 µ, LP 125 w, LET 120 µs, SS 90 µm.	30.038 HV	625.54	–
12	LT 30 µ, HD 50 µ, LP 150 w, LET 130 µs, SS 90 µm.	31.14 HV	229.857	–
13	LT 30 µ, HD 50 µ, LP 150 w, LET 140 µs, SS 90 µm.	29.73 HV	217.33	–
14	LT 30 µ, HD 50 µ, LP 150 w, LET 150 µs, SS 90 µm.	29.98 HV	123.05	–
16	LT 30 µ, HD 50 µ, LP 175 w, LET 120 µs, SS 100 µm.	28.45 HV	191.16	–
17	LT 30 µ, HD 50 µ, LP 175 w, LET 130 µs, SS 100 µm.	29.87 HV	191.54	–
18	LT 30 µ, HD 50 µ, LP 175 w, LET 140 µs, SS 100 µm.	30.15 HV	535.21	–
19	LT 30 µ, HD 50 µ, LP 175 w, LET 150 µs, SS 100 µm.	30.24 HV	208.16	–
5	LT 30 µ, HD 50 µ, LP 100 w, LET 160 µs, SS 70 µm.	–	–	0.5kg-108µm,0.4n 1kg -347 µm,1.4n 1.5kg-324 µm,1.0n
10	LT 30 µ, HD 50 µ, LP 125 w, LET 160 µs, SS 80 µm.	–	–	0.5kg-222 µm,0.1n 1kg -240 µm,1.7n 1.5kg-556 µm,1.2n
15	LT 30 µ, HD 50 µ, LP 150 w, LET 160 µs, SS 90 µm.	–	–	0.5kg-161 µm,0.5n 1kg -789 µm,0.9n 1.5kg-239 µm,2.4n

For all the samples the laser power, exposure time of laser and spot size is varied.

- The porosity of all the samples (except 5, 10, and 15) is observed and the low porosity is obtained for sample 14, corresponding process parameters are laser power 150 w, laser exposure time 150 µs, spot size 90 µm and
- The high porosity is obtained for sample 9, the process parameters are laser power 125 w, laser exposure times 150 µs, spot size 80 µm are used.

- The maximum hardness value is sample 8 at the laser exposure time 140 µs, spot size is 70 µs laser power is 100w and minimum hardness value obtained for the sample 16 and the laser exposure time 120 µs, spot size is 100 µm and laser power is 175w are used.
- Among the 5th sample shows at 0.5kg, to use process parameters laser power 100W, laser exposure time is 160 µs, and spot size is 70 µm. the minimum values 108µm of wear loss, the frictional force is 0.4N
- Among the 15th sample shows at 1kg, to use the process parameters laser power 150W, laser exposure time is 160 µs, spot size is 90 µm. the maximum values wear loss of 789 µm, 0.9N is the frictional force.
- Process parameters used in the porosity were laser power, spot size and laser exposure time is decreases then we obtain a low porosity, laser power, spot size, laser exposure time is increases then we obtain a high porosity.
- Finally process parameters choosed in the hardness were laser power, spot size decrease and laser exposure time is increases then we will obtain a maximum hardness value. Laser power, spot size increase and laser exposure time is decreases then we will obtain a minimum hardness value.
- The process parameters of the wear resistance are laser power, spot size increase and laser exposure time is decreases then we will obtain a maximum wear loss & frictional force value and Laser power, spot size decrease and laser exposure time is increases then we will obtain a minimum wear loss & frictional force value.

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