Preliminary testing on effect of process parameters on LENS ™ SS316L Cylindrical components

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Abstract : Additive manufacturing produces metal parts at a faster rate and gives designer freedom. LENSTM produces metal parts from 3D CAD model with much accuracy and a faster rate.The effect of process parameters which affect porosity, micro hardness along each layer and also on the top layer of the metal were studied. Variation of microstructure with the variation of heat was studied

IndexTerms - ***SS316L, microstructure, micro hardness, porosity***

I. INTRODUCTION

LENS^{TM} is an additive manufacturing technique thatproduces metal parts layer by layer. It uses fibre diode laser to cure the metal powder. The porosity, micro hardness and microstructure of the deposits depends on the process parameters like Laser Power, Scan velocity, Powder Flow Rate and Working Distance. Earlier studies found that these process parameters influence the properties of the final product. This study was an attempt to understand the influence of the process parameters on the properties. Design of experiments was used for optimization of the properties. ANOVA table was used for depositing the metal products

In this paper there was a study on the effect of process parameters on micro hardness, porosity. Microstructure was observed on most of the layers of the sample from top to bottom and reasons for the such microstructure was identified

Experimental setup

Laser engineered net shaping (LENS) is an additive manufactured process that produces metal parts in a controlled argon atmosphere. It is a process where metal parts produced from a CAD model.

Initially the CAD model was designed in Pro-E software, and then it was converted into STL format. After checking the errors, then the part was oriented in software which is preinstalled in LENS 750R machine. Then the part was built and then after cooling the part was removed from SS304 substrate which is about 5 mm thickness.

The fibre optic laser has a wavelength of 1070 nm. The beam diameter was about 71 µm which was calculated using fibre optic formulae.SS316L alloy powder was injected into argon controlled process chamber through nozzle head. The nozzle head has 4 nozzles which were arranged in such a way that all powder meets and falls on the substrate. Flow of the powder was maintained by flow meter.The diode laser cures the metal powder. CNC platform was programmed by using different hatching patterns

The powder flow rate, Laser power was calibrated before doing the experiment

In the present work there were three process parameters like Laser power, Scan Velocity, Powder flow rate with three variables of each was deposited. The working distance was kept at 7.5mm and laser power was fixed to 400W for better deposits.9 cylindrical deposits were deposited according to design matrix with size of 15mm height and 10mm diameter. The measured was analyzed using ANOVA. Microstructure was observed after the sample was cut longitudinally and prepared metallurgically at different layers of sample. The microstructure was observed along longitudinal direction and also on the top layer of each layer. Three readings were taken on each layer. The porosity and bulk density was calculated using Archimedes principle for all the samples.

Table 1. Design matrix showing different process conditions

Serial no.	Laser power(W)	Powder flow rate(g/min)	Scan velocity (mm/s)
01	400	10 (15)	8
02	400	15 (21)	8
03	400	20 (26)	8
04	400	10 (15)	12
05	400	15 (21)	12
06	400	20 (26)	12
07	400	10 (15)	16
08	400	15 (21)	16
09	400	20 (26)	16

Results and discussion

Table2. Design matrix showing different process parameters and corresponding experiment top layer hardness and porosity values

Serial no.	Laser power(W)	Powder flow rate(g/min)	Scan velocity (mm/s)	Cross section Hardness (VHN)	Top layer Hardness (VHN)	POROSITY
1	400	15	8	132.86	159	6.062
2	400	21	8	150.4	143.6	7.942
3	400	26	8	155.9	139.3	5.3861
4	400	15	12	155.01	168.3	3.0888
5	400	21	12	150.9	165.3	6.9554
6	400	26	12	152.3	152.9	6.3956
7	400	15	16	169.6	180.8	6.5099
8	400	21	16	152.6	158.2	7.6999
9	400	26	16	166.6	145.4	6.0345

Porosity

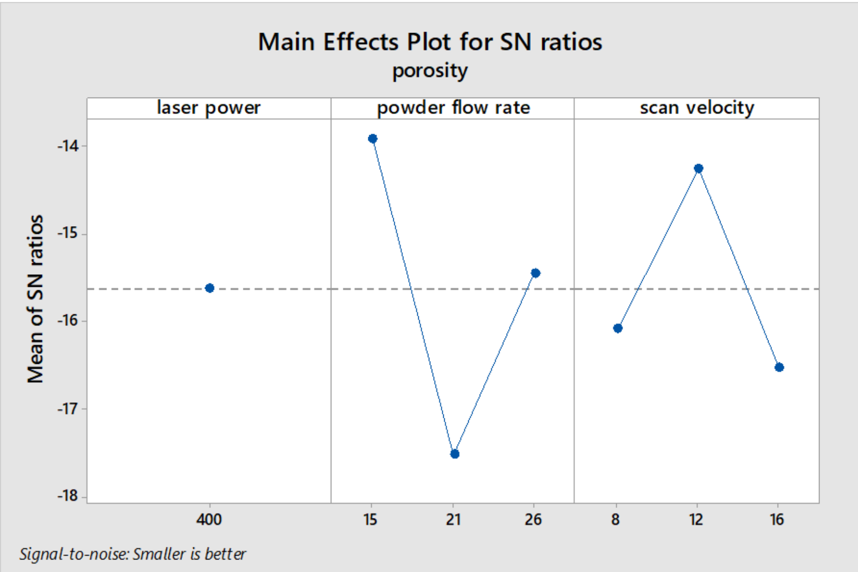

Fig1. Contour plot for SN ratio for porosity

Table3. Main effects table for SN ratio for porosity

level	Laser power(W)	Powder flow rate(g/min)	Scan velocity(mm/s)
1	-15.63	-13.91	-16.09
2		-17.52	-14.25
3		-15.45	-16.54
delta	000	3.62	2.28
rank		1	2

But the results of samples are porous and porosity is 3 percent minimum and 8 % maximum. The sample which is having less powder flow rate and medium scan velocity got least porosity. For high powder flow rate, low scanning velocity and high power the porosity is lower. Bulk density is calculated and maximum bulk density was comparable to that wrought alloy. However, the LENS^{TM} sample density is lower side of wrought alloy range due to melting and solidification of powders and bulk density depends on so many factors and process parameters like laser power,scan speed, powder flow rate, layer thickness, and working distance etc. Bulk density obtained is almost 7.78 gm/cm^3 and is almost comparable with powder density 7.78 - 8.03 gm/cm^3.

Micro hardness

The micro hardness testing was done by using instrumented hardness tester with an indentation on each layer. The micro hardness was also taken on the top layer of each sample to evaluate the variation of hardness at different locations of the layer.

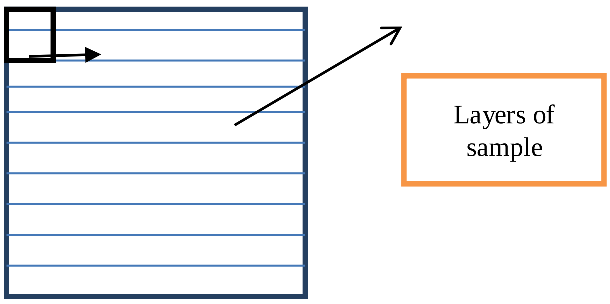

Fig 2.layers of sample showing how microstructure was taken

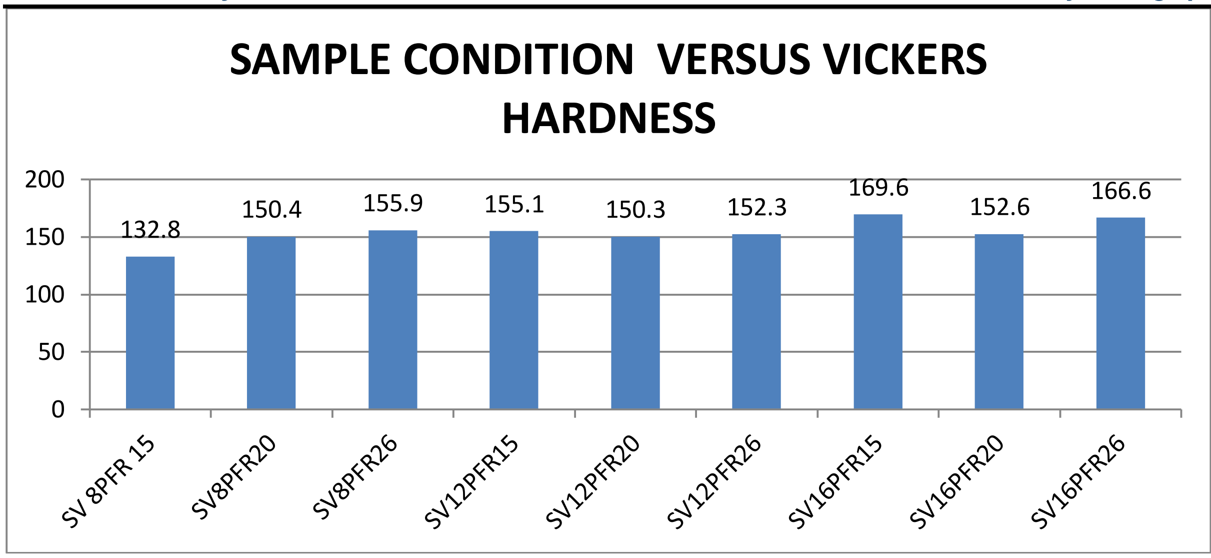

Fig3.contour graph showing the variation of Vickers hardness with sample condition

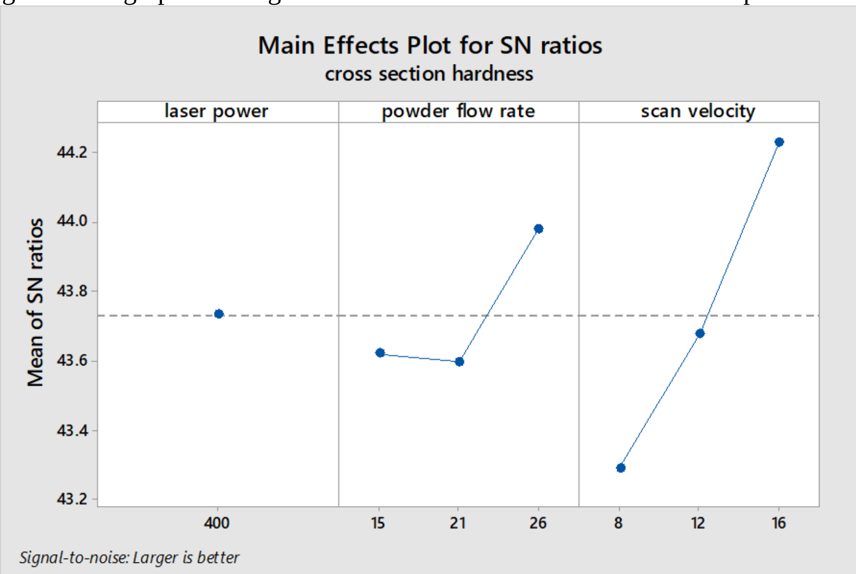

Fig 4.contour graph for SN ratio for cross section hardness

Table 4.Main effects table for SN ratio

level	Laser power(W)	Powder flow rate(g/min)	Scan velocity(mm/s)
1	43.73	43.62	43.29
2		43.60	43.68
3		43.98	44.23
delta	000	0.38	0.94
rank		2	1

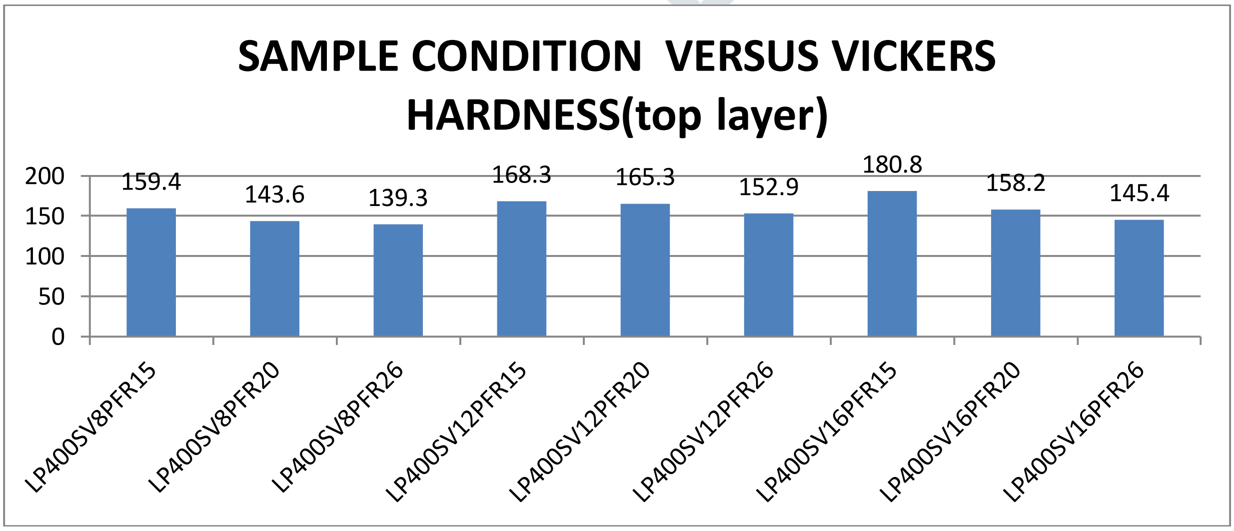

Fig5.contour graph showing variation of top layer hardness with sample condition

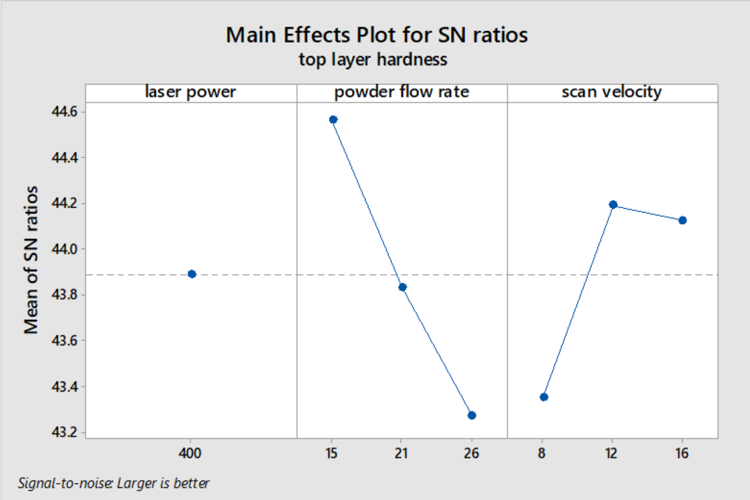

Fig 6. Contour plot of SN ratio for top layer hardness

Table 5.Main effects table for SN ratio

level	**Laser power(W)**	**Powder flow rate(g/min)**	**Scan velocity(mm/s)**
1	43.89	44.56	43.35
2		43.83	44.19
3		43.27	44.13
delta	000	1.29	0.84
rank		1	2

Average hardness values shows that for a high scan velocity and less powder flow rate there is higher hardness.
As the scan velocity increases the energy input into substrate was less so the cooling rates were high leading to high hardness. When the powder flow rate is more the interaction time between laser and powder will be more leading to low cooling rates which result in low hardness.
The localized heat interaction between laser and powder leads to thermal gradient, solidification rate and rapid cooling. Hardness behavior mainly depends on high temperature and cooling rate. Rapid cooling gives smaller size which leads to better hardness

Micro structure

Micro structure was taken for all the samples at almost all layers of sample and also on several locations on each layer systematically from left to right.

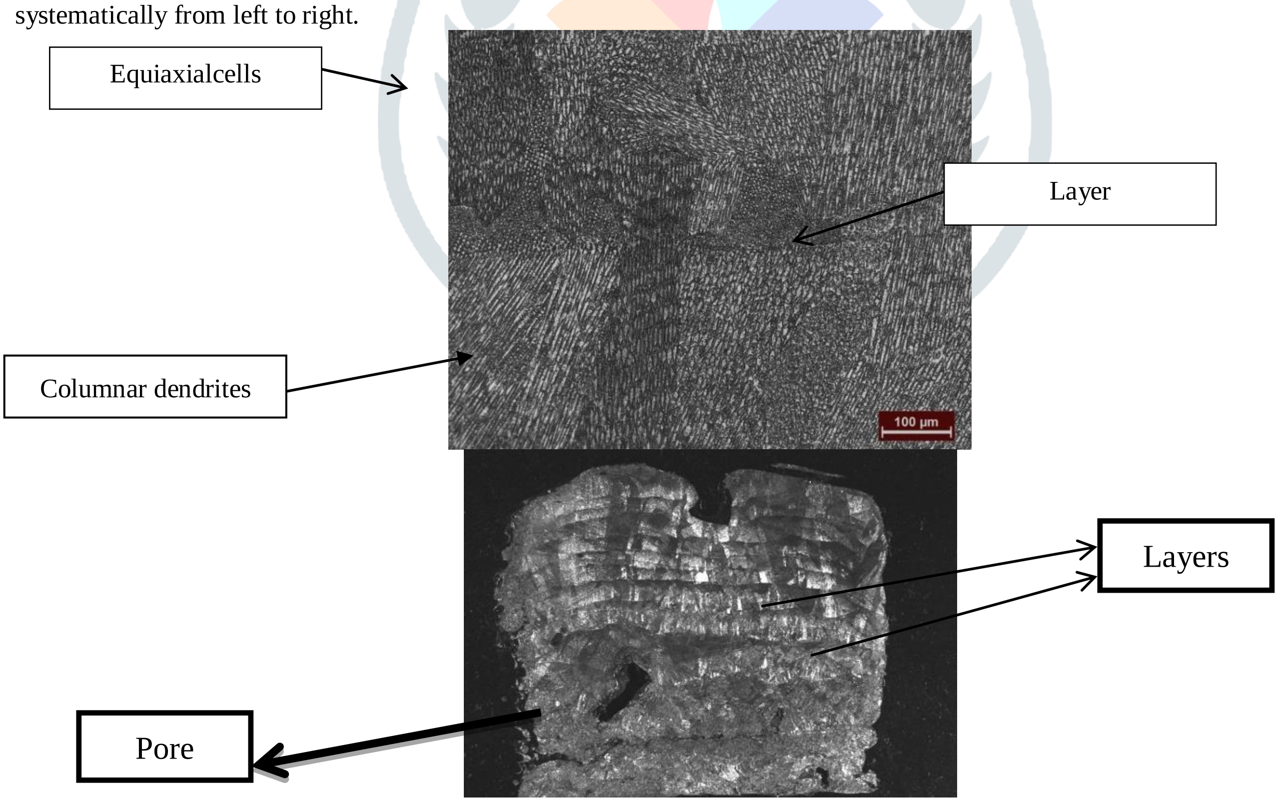

Fig 7.microstructure showing layers of samples

The Grain structure varies with cooling rates, if the cooling rates are fast the cell structure will be small.The phase represents eutectic phase and the bright phase represents austenite and dark represents ferrite. SS316L products are austenitic structure and an amount of ferrite phase.
The microstructure of sample having highest scan velocity and highest powder flow rate (PFR 26g/min SV 16 mm /sec)

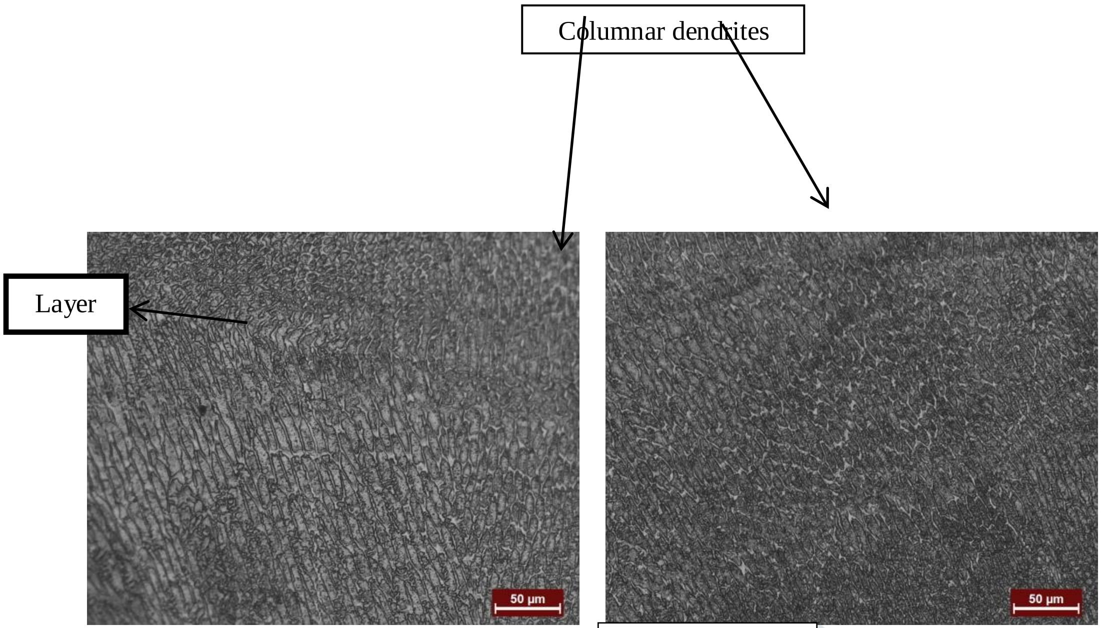

Fig8. Microstru PFR 26g/min SV 16 mm /sec)

The microstructure of sample having higher scan velocity and lesser powder flow rate (PFR 15 g/min SV 16mm/sec).Microstructure showing equiaxed cells and columnar grains variation of sample

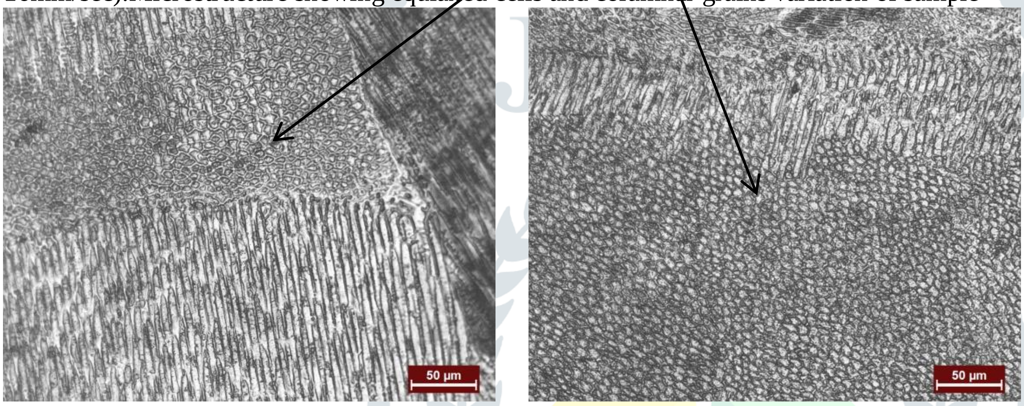

Fig9. Microstructure of sample (PFR 15 g/min SV 16mm/sec)

The microstructure of the sample having lower scan velocity and higher powder flow rate (PFR 26 g/min SV 8 mm/sec) consists of equiaxial cells

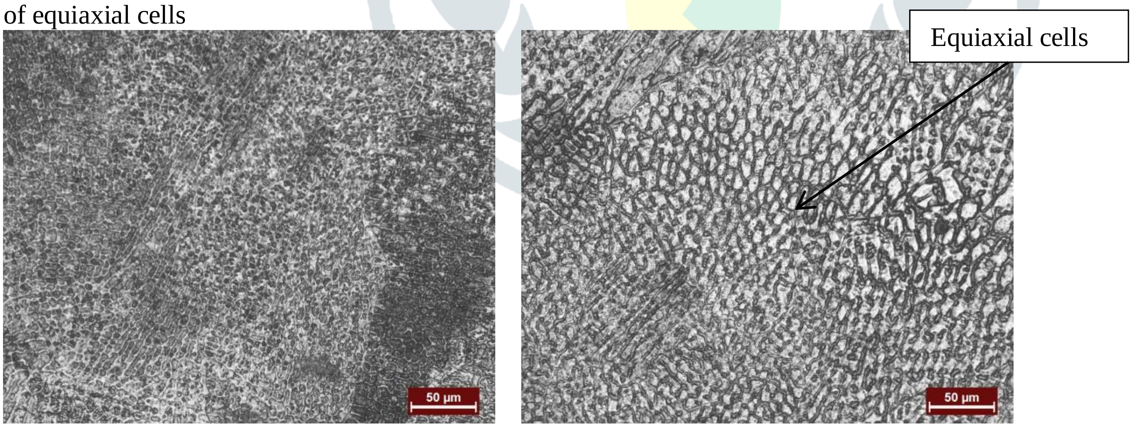

Fig 10.the microstructure of the sample (PFR 26 g/min SV 8 mm/sec)

The microstructure of the top layer of the sample having lower scan velocity and lower powder flow rate(PFR 15 g/min SV 8 mm/sec)& micro structure of the sample showing melt pools (PFR 21g/min SV 8 mm/sec)

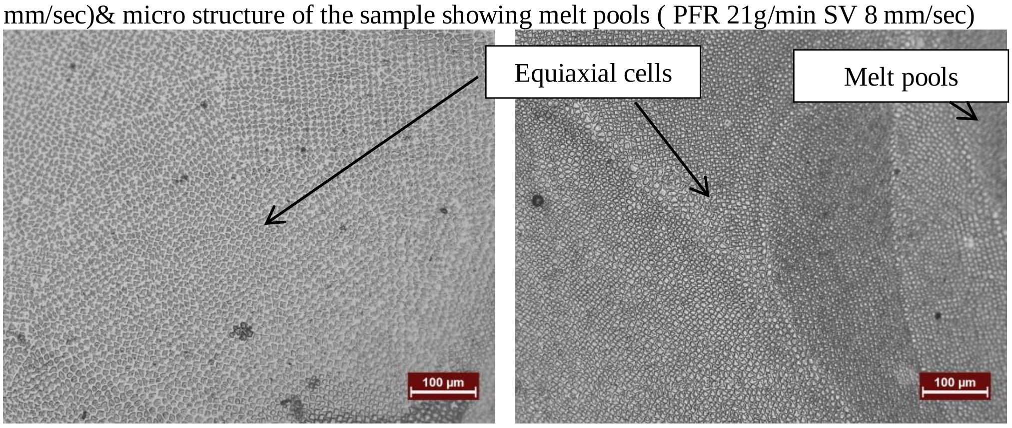

Fig 11.the microstructure of the sample (PFR 15 g/min SV 8 mm/sec) &(PFR 21g/min SV 8 mm/sec)

The microstructure of the sample having the top layer of the sample (PFR 21g/min SV8 mm/sec) and also on the inner layers of the sample

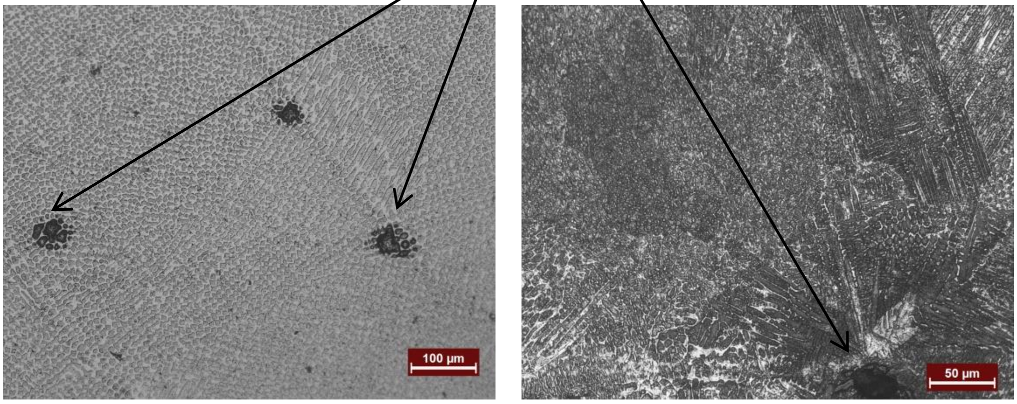

Fig 12.Microstructure of the sample (PFR 21g/min SV8 mm/sec)

Conclusions

SS316L metal specimens were deposited using LENS™ .The effect of process parameter on porosity and hardness was determined using Design of Experiments. Microstructure of deposits consists of ferrite transformation with equiaxial cells and columnar dendrites. The effect of process parameters like laser power, scan velocity was significant in cross sectional hardness, top layer hardness but in case of porosity powder flow rate was also significant

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