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An Experimental Investigation & Analysis of Gear Component Manufactured By 3D Printing & Conventional Process

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***Abstract*— Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. It clearly distinguished from conventional methods of material removal. A range of different metals, plastics and composite materials may be used. The mechanical properties like strengths and manufacturing complex geometry with lattice structure of Additive Manufacturing is the limitations of conventional manufacturing. The technology is gaining interest where a new approach to design and manufacturing is required. It enables a design-driven production manufacturing process, where design determines production and not the other way around. The aim of the paper is to carry out the analysis of 3D printed material and commercial wrougth material in reference to its mechanical properties i.e density and tensile strength.The main purpose is to produce additive manufacture components with low porosity which mainly drive the mechanical properties like the mechanical strength, fatigue strength and the elongation to rupture .Designing and manufacturing of the gear component in 3d printing is achieved using the derived results for low porosity.**

Index Terms—3D printing, conventional method, mechanical density, physical properties, gear manufracturng.

I.INTRODUCTION

As additive manufacturing (AM) evolves from Rapid Prototyping (RP) to the end-of-use product manufacturing process, manufacturing constraints have been largely alleviated and design freedom for part consolidation is extremely broadened. Selective laser sintering/melting (SLS/SLM) is a manufacturing process where parts without any special tooling are made directly from 3D CAD data. SLS/SLM is advantageous in comparison with the other methods for manufacturing parts with complex geometry and light weight inner structures. SLM technology is designed to produce near-full-density objects with mechanical properties comparable to those of bulk materials and to offer significant time savings by eliminating or considerably reducing post-processing steps. Layer manufacturing technology exhibits a high potential in the field of rapid manufacturing, due to its capability to directly build up three-dimensional metallic components. Additionally AM enabled part consolidation which promises a more effective way to achieve part count reduction and the ease of assembly compared with traditional Design for Manufacture and Assembly (DFMA) method.

The project is supported and carried in Nashik Engineering Cluster (NEC).The industry is situated in Ambad MIDC Area.3D Printing EOS M270 Machine is established in Rapid Prototyping department of NEC . RPT Department sir Prashant Chaudhari, Nikhil Jadhav, and R&D Department Sir Tushar Bhandare gave their valuable time and suggestions for the completion of the project. Review paper of project published on Volume-3, Issue-1, Jan, 2016 of International Journal for Research in Emerging Science and Technology (IJREST) (e-ISSN 2349-7610).

Benefits

The strengths of Additive Manufacturing lie in those areas where conventional manufacturing reaches its limitations. The technology is of interest where a new approach to design and manufacturing is required so as to come up with solutions.

- It enables a design-driven manufacturing process, where design determines production
- Allows for highly complex structures which can still be extremely light and stable.
- High degree of design freedom
- Optimization and
- Integration of functional features
- Manufacture of small batch sizes at reasonable unit costs
- High degree of product customization even in serial production.

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II.LITERATURE REVIEW

Sheng Yang, Yunlong Tang, et.al [1]explains, a new part consolidation method considering functional integration and structure optimization. The authors explained to improve performance, heterogeneous lattice structure was introduced They studied the performance and functionality of a triple clamp to verify the proposed methods .results showed that part count was reduced by 19 to 7 and weight by 205 was achieved.The results highlight and demonstrate the functionality and performance improvement.

D. Cooper , J. Thornby , et.al [2],examines potential benefits of ALM such as reduction of components weight. Example of Internal Combustion engine or exhaust valves are manufactured by reverse engineering using Micro-computed Tomography (µCT)scanner and was redesigned using FEM ,for designing light weighted structure .The case study demonstrated reduction of 20% weight i.e. 9.4gm ,compared to original equipment manufacturer (OEM) component.

Martin Baumers, Phill Dickens, et.al [3], explains the improvement in rapid prototyping technology (RPT) to develop efficient functional parts. The numerical tools are discussed in detail for both design requirements and manufacturing specificities of thin walled metal parts as a case study. This methodology optimized the manufacturing paths to propose a realistic CAD model in parallel with the corresponding manufacturing program.

Josef Sedlaka, Daniel Rican, et.al [4], focuses on the analyses of materials produced by direct laser sintering and classical additive method (i.e powder metallurgy).Detailed study of principles of direct metal laser sintering and their properties were done .He developed samples, analyzed them through light and electron microscopy and testing was carried by mechanical tensile test and Vickers hardness test .Results showed that hardness values of DLMS showed almost no pores and inclusion but huge amount of disruptions complex dirt.

I. Yadroitsev , I. Shishkovsky , et.al [5], studied the SLM process for 3D printed parts with near to net shape and internal geometry design at their computer modeling stage. They discussed the relation between laser operational parameters, computer designs of the manufactured Objects, composition and microstructure for attainment of fine porous structures. Results improve efficiency due to the porous structures on the material filtering.

A. Riemer, S. Leuders , M. Thone, et.al [6] discussed the direct manufacturing techniques of individual and complex components but these components suffer from imperfections mostly micro pores and high residual stresses. The test conducted for fatigue load showed that these imperfections lead to premature failure and low performance. 316L stainless steel was investigated for fatigue performance which showed satisfactory results similar to conventionally processed stainless steel.

C.P. Paul , S.K. Mishra, et.al [7],determined mechanical and microstructural properties of 316L stainless steel fabricated by Direct Laser Deposition (DLD) and compared with those of conventionally built counterparts .The author fabricated nine cylindrical specimens in vertically upward direction using Laser Engineered net shaping (LENS) DLD system. Results indicate that the DLD samples have higher yield and ultimate tensile strength compared with the wrought forms.Long local time interval showed higher uniform strength and low elongation to failure but the porosity and less integral to microstructure bonds are more prevalent in locations further upward from the build plate .Converse effects were realized for shorter time intervals .

G. Bi, C.N. Sun, A. Gasser, et.al [8], measured the process monitoring and control in Laser Additive Manufacturing (LAAM). Results revealed that the geometry affects the melt pool temperature ,mostly where heat dissipation is limited. Laser beam can be defocused only to a certain extent to avoid insufficient power density ,which can cause clad surface and clad layer. During process control surface oxidation should be avoided as it detoriates the LAAM process .Using path dependent process control dimensional accuracy of the deposited model can be improved.

C. Sanza, V. Garcia Navasa , et.al [9], demonstrated analytical and experimental studies for different processing parameters for laser rapid manufacturing (LRM) in vertical direction using AISI304 stainless steel. Their investigations results that the rounded bulging phenomenon of the manufactured layer in downward direction was significant for scan speeds less than 200mm/min.Thus surface finish of vertical configuration was found better than that of horizontal for the same setup of LRM.

III .PROBLEM STATEMENT

The conventional manufacturing processes all demand subtracting material from a larger block whether to achieve the end product itself or to produce a tool for casting or moulding processes and this is a serious limitation within the overall manufacturing process. For many applications traditional processes impose a number of unacceptable constraints, including the expensive tooling as mentioned above, fixtures, and the need for assembly for complex parts. In addition, the subtractive manufacturing processes, such as machining, can result in up to 90% of the original block of material being wasted. Thus it is essential to introduce a process which can produce complex, low weight, comparative high strength components. Aerospace’s stringent requirements and need for weight reduction provide the context for developing AM .Removing just one pound of weight from each aircraft in American’s fleet would save more than 11,000 gallons of fuel annually AA flies 619 aircraft therefore 1 pound weight reduction on just one aircraft yields [3].

IV.OBJECTIVE

The main objective is to manufacture components with ease, more stronger and light weight for various applications.

Manufacturing of complex end product in one stroke can be effectively achieved by 3D printing.
i) To Study 3DPrinting Process.
ii) To evaluate Physical properties of 3D Printed and Convention process.

- Microstructure
- Density

iii) To evaluate various Mechanical properties of component manufactured by 3D Printing and Conventional Machine.
v) Competent Manufacturing Process

V. Additive Manufracturing

Additive Manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. The technology has especially been applied in conjunction with Rapid Prototyping-the construction of illustrative and functional prototypes. It gives Original Equipment Manufacturers (OEMs) in the most varied sectors of industry the opportunity to create a distinctive profile for themselves based on new customer benefits, cost-saving potential and the ability to meet sustainability goals.[2]

A. Abbreviations and Acronyms

AM	Additive Manufacturing
LAM	Laser Additive Manufacturing
DLSM	Direct Laser Selective Melting
$V_{Process}$	Process Velocity,
Lt	Layer Thickness,
V	Laser Scanning Velocity
H	Hatch Distance.
ED	Energy Density,
P	Laser Power,
V	Laser Scanning Velocity,
Lt	Layer Thickness,
WDA	Area Of Penetrated Bead,
BW	Bead Width,
PD	Penetration Depth

B.Functional Principle

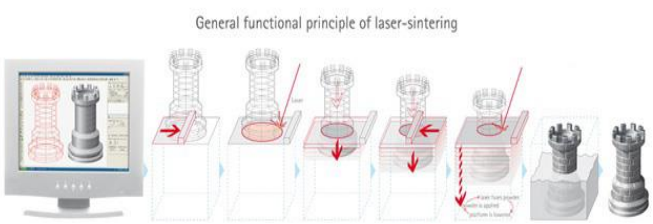


Fig no.1 Functional Principle

The system starts by applying a thin layer of the powder material to the building platform. A powerful laser beam then fuses the powder at exactly the points defined by the computer-generated component design data. The platform is then lowered and another layer of powder is applied. Once again the material is fused so as to bond with the layer below at the predefined points. Depending on the material used, components can be manufactured using stereo lithography, laser sintering or 3D printing.

VI. Aim and Purpose of Study

To study the dependence of efficiency of additive layer manufacturing on various process cycle parameters and thus find out the efficient way to improve efficiency of the LAM process. Interaction of laser beam and powder material was also considered, as of it is such a fundamental understanding of process gives further aspect to analyze what are real factors affecting process efficiency. Manufacturing of test pieces by varying input parameters such as laser power and scanning speed and the formation and penetration of formed single tracks were studied. Test pieces were manufactured by SS 17PH1. Most efficient process cycle is determined. Designing of gear component was done and analysis of its mechanical properties in comparison to conventional manufactured gear was achieved.

VII. Discussion

A.EOSINT M 270 Specifications

SLM technology is used in the above 3D printing machine EOSINT M270 can manufacture parts with the desired microstructure as well as macrostructure.

Table no.1 Machine Specifications [21]

System model	**EOSINT M 270**
Beam type	Yb- fibre laser
Focus System	Dual Focus
Beam power	200 W
Build material used for this research	Stainless Steel, PH1
Material density	7.8 g/cm3
Nominal build volume size, X × Y × Z	250 mm × 250 mm × 215 mm
Usable build area, X × Y	225 mm × 225 mm
Layer thickness	20 – 60 micron layer thickness
Tolerance	20 – 50 micron tolerances
Process atmosphere	Nitrogen
Part retrieval	Wire erosion
Manufacturer reference	EOS GmbH EOS GmbH (2013)

Fig no.2 EOSINT M270 Machine[21]

B.Process Efficiency

In additive manufacturing process cycle time can be divided in two main categories i.e primary time and auxiliary time . To study laser additive manufacturing process efficiently the two

process cycle time should be studied. Primary time consists of time needed to melt the each layer of desired geometry. Auxiliary time consists of building plate lowering and powder spreading .Studies from literature (Schleifenbaum et al. (2011) focused on investigating on primary parameters because 80% of the time is utilized in processing large volume parts .Thus built rate is important while studying additive manufacturing. Thus Schleifenbaum et al. (2010) suggested governing equation which include layer thickness, scanning velocity and hatch distance are affecting to build rate, as equation 1

$V_{Process} = V * LT * v * h$ (1)

where,

$V_{Process}$ process velocity,
LT layer thickness,
v laser scanning velocity,
h hatch distance.

Yadroitsev and Smurov (2010) investigated that one way to study process efficiency of LAM is to examine single track formation which aim is to define energy density needed to melt the single tracks. Understanding of the mechanisms of single track formation in powder bed fusion (PBF) process gives basis for usage of wider range of commercially available powders and also basic knowledge to improve process efficiency by modifying the parameters of the building process .According to study by Ciurana et al. (2013), energy density which is used in building process can be determined with equation 2.

$$ED = \frac{P}{v * LT * h} \quad (2)$$

Where

ED energy density,
P laser power,
v laser scanning velocity,
LT layer thickness,
h hatch distance.

Using the above equations the energy density and Laser interaction time is calculated in table (2)

VIII. Experimental Part

Material composition

Carbon,0.09 max, Manganese ,1.00 max, Phosphorus,0.040 max, Sulfur ,0.030 max, Silicon ,1.00 max ,Chromium, 16.00 - 18.00

A. Model for interaction between laser beam and powder material

Model was prepared to verify the results of (Ville Matilainen ,et al 2014) were he found out the relation between different process parameters. Model created with single track were made on top of 20 x 40 x 15 mm bulk piece.

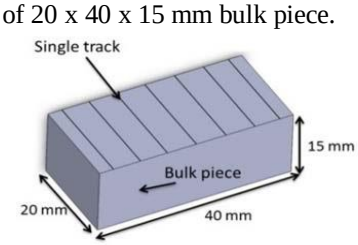


Fig.no 3. 3D Model of the single track test piece.

This all enables further development of model for laser beam and material interaction and deepens understanding of basic phenomena occurring during laser additive manufacturing of metallic materials.

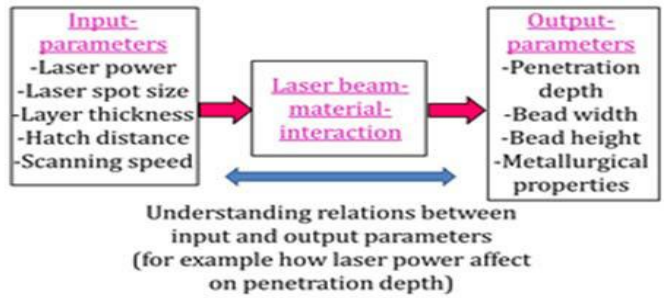


Fig. 3. Model for interaction between laser beam and powder material in LAM.[12]

Analysis on the test pieces was carried out such as the pieces were 1st cut into longitudinal direction and then polished .These polished surfaces were photographed with optical microscope and the penetration depth, width and height of the bead of the single tracks were measured with AxioVision LE64 microscopy software. For 200W table below shows building parameters in single track tests executed at LUT Laser.

Table no.2 Building parameters in single track tests performed at LUT Laser with laser power of 200 W.[12]

Parameter	*St-3*	*St-2*	*St-1*	*St0*	*St1*	*St2*	*St3*
Laser power [W]	200	200	200	200	200	200	200
Scan speed [mm/s]	1600	1400	1200	1000	800	400	600
Layer thickness [mm]	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Laser spot size [mm]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Energy density [J/mm^3]	63	71	83	100	125	167	250
Laser interaction time [s]	6.3* 10-5	7.1* 10-5	8.3* 10-5	1*10-4	1.3* 10-4	1.7* 10-4	2.5* 10-4

B. Equations used in analysis

For making the rough penetrated bead surface able to evaluate properties of the single track with other parameters. Hence area of penetrated bead WDA was calculated as

$WDA = BW * PD$

where

WDA area of penetrated bead,
BW bead width,
PD penetration depth.

Relation between in input and output parameters obtained from the research by (Ville Matilainen ,et al 2014) as below

a)PD= 0.73*Ed
b)WDA= $8*10^{-5}$ Ed

C.Selected parameter for manufacturing

Manufacturing was carried out in Nashik Engineering Cluster ,Ambad ,Nashik (NEC) .Depending on these results obtained the best combination of process cycle parameters was selected to obtain high density, good mechanical strength component. The cube size of 10*10*10 mm^3 is manufactured using process parameters as laser power 200W (EOS M270 machine specification),scan speed 300 mm/s, hatch distance 0.12 mm, layer thickness 20 microns

D.Testing

1).Density measurement

The quality of a part contains parameters out of at least three main topics, which are to some degree interdependent: mechanical parameters (density, mechanical strength, elongation to rupture, fatigue strength), surface quality and dimensional accuracy. The most economical way to get information about the mechanical parameters is the measurement of the density of the part under consideration, as the porosity 1 directly affects the mechanical strength, fatigue strength and the elongation to rupture (Gilbert and Rooy, 2004)

Density measurement techniques
1.1. Archimedes method
For the Archimedes method, a Mettler balance (Type AE200) with a specific density measurement device for solid materials was used **.**

Fig no.4 METTLER TEDELO[19]

1.2.Principle

The density is the quotient of the mass m and the volume V.

$$\rho=\frac{m}{v}$$

Density determinations are frequently performed by Archimedes' principle, which is also used with the density determination kit for the balances. This principle states that every solid body immersed in a fluid apparently loses weight by an amount equal to that of the fluid it displaces. The procedure for the density determination by Archimedes' principle depends on whether the density of solids or liquids has to be determined.

1.3. Fundamentals

The density of a solid is determined with the aid of a liquid whose density 0 is known (water or ethanol are usually used as auxiliary liquids). The solid is weighed in air (A) and then in the auxiliary liquid (B). The density can be calculated from the two weighing's as follows[18,19]

$$\rho=\frac{A}{A-B}(\rho_0-\rho_l)+\rho_l$$

$$V=\alpha\frac{A-B}{\rho 0-\rho l}$$

ρ = Density of the sample
A = Weight of the sample in air
B = Weight of the sample in the auxiliary liquid(Acetone)
V = Volume of the sample
ρ_0= Density of the auxiliary liquid
ρ_l = Density of air (0.0012 g/cm3)
α = Weight correction factor (0.99985), to take the atmospheric buoyancy of the adjustment weight into account.

1.4. 3d Printed Component

Readings for accuracy the cube component was measured 4 times in water and acetone.
Water
Density (%) 99.53 ,99.52 ,99.55,99.28
Mean Density (%) 99.53
Acetone
Density (%) 99.23 ,99.40 ,99.41,99.20
Mean Density (%) 99.39

Mean Density value 99.46%
Thus from results their exists 0.5% porosity which is unavoidable according to (Spierings and Levy, 2009)

1.5. Conventional Component
Density Measurement
Water
Density (%) 99.95 ,99.91 ,99.95,99.82
Mean Density (%) 99.90

Acetone
Density (%) 99.85 ,99.87,99.80,99.75
Mean Density (%) 99.95

Mean Density value 99.92%
Almost No Porosity i.e 0.08%

E.Tensile testing.

Tensile specimens were manufactured using the studied process parameters and tests were conducted on Universal Testing machine. Testing was conducted in NEC ,Nashik.
UTS for 3D material in XY direction-630MPa.
UTS for conventional material-579 MPa.

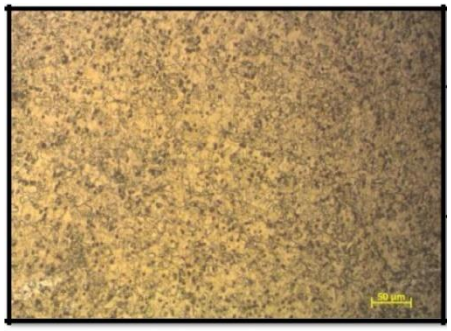
F. Micrographs check of cross section:
The specimen prepared were analyzed by vertically cutting the sections of the cube parallel to base .The cross section of the cube was examined using 4 different magnification. The microstructure test was carried out in NEC Nashik testing lab using Zeiss Axio Observer instruments. The pictures were analyzed according to the resolution and the illumination of the samples, a suitable preparation of the black-and-white micrographs is needed. Therefore, remaining scratches of the polishing treatment can be removed by adjusting the contrast and by using the brush tool. Furthermore, with selecting the right threshold values in the colors tool box, a clear identification of the pores is possible. When dealing with porous sample the determination of pores in microstructure is difficult. Thus in such cases, these pores need to be blackened manually. The correct black content (porosity) of the cross section can be identified using the in built histogram function.

1).3d Printed Component

Microstructure of 200µm magnification

Process Parameters
P =200W
V_{scan} = 300 mm/s
Layer thickness= 20 microns
Black spots shows the presence of porosity about 0.46%
Presence of retained austenite, with more amount of ferrite which contributes to give high strength .

2.) Conventional Component
Microstructure with 50µm magnification



No Porosity is observed i.e 0.07%
Martensitic Matrix with uniform distributed Carbides structure is observed, with low ferrite particles which can predict less strength compared to 3D printed material.

G. Manufracturing Of Gear

Design a helical gear was done using the input conditions are power, speed, helix angle, gear ratio. Procedure for designing was taken from PSG Design data book .Input parameters for design are i.e Power P = 3 KW, Speed of Pinion N = 1200 rpm, Gear Ratio i =2, Helix Angle, β = 15º

	Variable name	**Description**	Value	Units
1	Z	NO. of Teeth	41	
2	M	Module	1.5	mm
3	D	Pitch diameter	60	mm
4	PH1	Pressure angle	20	degree
5	B	Helix angle	15	degree
6	F	Face width	10	mm
7	A	Addendum	62.7	mm
8	D	Dedendum	1.25*A	mm
9	P	Power	3	kw
10	N	Speed	1200	Rev/min

Table no.3 Gear parameter

1).Designing in Creo
Using parametric programing the helical gear was modeled in Creo.

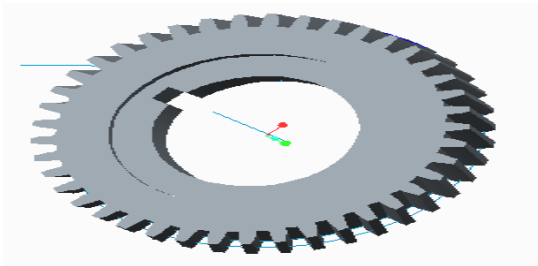


Fig no.5 Creo Model

2).Manufacturing in EOS M270

By using the obtained best process parameters the gear was manufactured in 3d printing EOS Machine.

Flow Chart Of 3d Printing

Gear Molding in Creo
↓
Import of Gear Stl, to 3d Magic Software
↓
Preparation of Building Platform
↓
Support Generation
↓
Importing the Component to EOS PSW Software
↓
Actual Visualization of the Slicing Process
↓
Printing of the Component

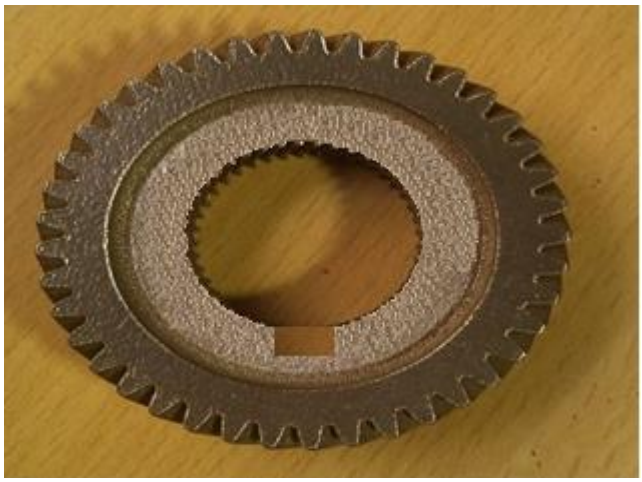


Fig no.6 3D Printed Gear

3).*Manufacturing by Conventional Process*

Gear Hobbing process was used to conventionally Manufacture Gear

Fig no.6 Conventionally Manufractured gear

IX. Results And Discussion

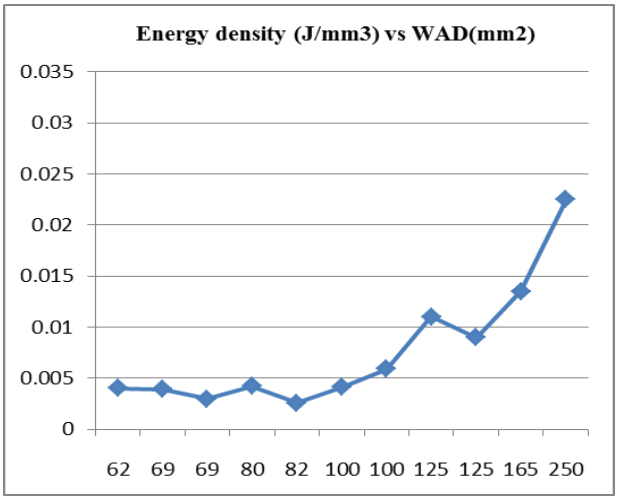
A.Relation Between Input And Output Parameters .

The fundamental analysis of process efficiency during the LAM process can be improved and understanding gathered during study leads to deeper understanding of whole interaction model, especially relations concerning input parameters and output parameters. When understanding the relations of input and output parameters of this model (see Fig. 1), such as energy density input, laser interaction time, penetration depth and *WDA*, it is possible to evaluate and analyze the process efficiency*(*Ville Matilainen ,et al 2014)the relation can be shown. By Regression analysis of input and output Ville Matilainen ,et al derived relationship

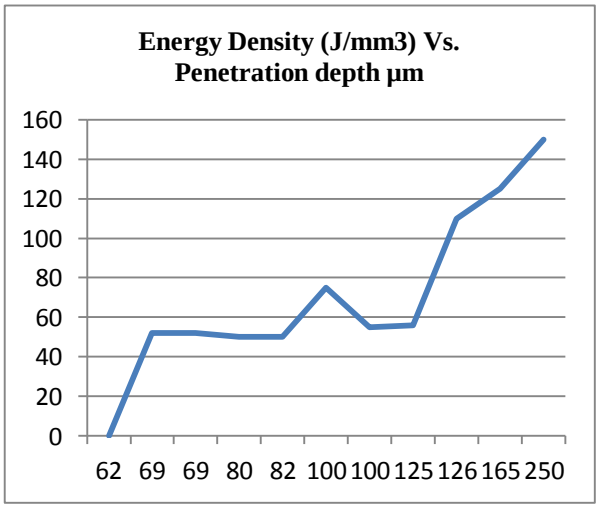
a)PD= 0.73*Ed

b)WDA= $8*10^{-5}$Ed

Thus these relation or equations could then act also as tool for evaluation of process efficiency.



Graph 1.Energy Density VS WAD



Graph 2. Energy Density VS Penetration depth

B. Density Measurement

Using the efficient process cycle parameters the cubical block generated was tested for the presence of porosity using Density measurement techniques i.e. Archimedes Principle and microstructure analysis .The value of porosity for 3D printed cube is 0.5%. From results both method we can conclude that, the porosity measured in both methods is approximately same .Thus by additive manufracting 0.5% of porosity is present and is unavoidable by controlling the process parameters, while the conventional component results in negligible or no porosity.

C.Tensile strength Measurement.

The deformation induced in the 3D printed material stainless steels and conventional is different and has been studied extensively [14,15]. Because of the different phases, it is inappropriate to refer both the material as 17-4PH stainless steel, even though the powder is chemically consistent with the same composition. The fabrication by selective laser melting contains of stainless steel by 3D printing gives different phases significant quantities of retained austenite as opposed to all martensitic. Thus due to microstructure

variation and fine powder particle size, high tensile strength is obtained in 3D Printing Process.

CONCLUSION

Based on the investigation the aspects for increasing the process efficiency of laser additive manufacturing (LAM) process is more efficient when input-output parameter relations are more closely, examined ,since the process efficiency requires basic understanding and knowledge of these parameters. It was concluded from the study that the energy density plays important role while studying input and output parameters relationship. When energy density input is increased, the penetration depth, WDA also increases. Width-depth ratio, *WDR*, was calculated and it showed that the *WDR* is decreasing when energy density input increasing. Equations were created from the measurement data and it showed that it is possible to have rough estimations on the single track formation of 3D printing with these equations.

Measurement of density was easy, economical and fast using Archimedes principle. The microstructural investigation method is costly, time consuming and slow. Moreover deep knowledge is required to read the microstructural results. The results from both the methods showed similar value with a deviation of 0.1% in the readings. Thus using the efficient process cycle values, confirming minimum presence of porosity the helical gear is manufactured in EOS M270 Machine i.e ALM technique .Dimensional accuracy was maintained during the manufacturing process. Using same material SS-17PH1 gear was manufactured conventionally by hobbing process. The Tensile strength of 3D Printing Process is comparatively high because of the presence of retained austenite and fine grain structure. Hardness, Gear tooth bending tests are to be discussed and evaluated comparative for both 3D and conventionally built gear in future work. The only limitation for 3D Printing process is high initial cost , design of suitable designing procedure and 0.5 % porosity.

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