COMPARATIVE EXPERIMENTAL ANALYSIS OF PROTOTYPING OF 3D MECHANICAL COMPONENTS USING 3D PRINTING WITH CONVENTIONAL MANUFACTURING METHODS

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Abstract - *Conventional manufacturing is widely being used in current scenario but recently researchers and people from industry have done a lot of research and applied 3-D Printing using metals in practical applications like in the aviation industry, medical and arts. This paper is based on comparison of these two manufacturing techniques, conventional manufacturing using 4-axis CNC machine and 3-D Printing using RENISHAW AM 400; furthermore, the comparison is from the manufacturing point of view only. Comparison consists Lead time requirement for manufacturing, Electricity requirement for the manufacturing of same component, Total energy consumed in manufacturing of the component, steps involved in manufacturing of the same also effect of these two techniques on the environment in the form of carbon emission is presented in this study, complexity these two techniques that can handle and Manufacturing is also added presented in the paper.*

Key Words: Conventional Manufacturing, Additive Manufacturing, CNC Manufacturing, 3D Printing, Comparative analysis, DMLS method, Sintered process.

1. INTRODUCTION

3D printing, also referred as additive manufacturing, is a method of making a three-dimensional object from a CAD model or. The method of making these objects is additive. Within the additive method, an object to be written is built from the base-up by in turn adding it to layers of the development material. The additive method may be contrasted with the subtractive process, where material is removed from a block by methods such as sculpting or drilling. Though recently, there have additionally been innovation steps toward using materials like metals of various sorts and additionally organic matter like carbon and its varied derivatives even Nickel alloy powder and Titanium is used. The main principle of 3D printing is stereo lithography, outlined by Charles Hull in a 1984 patent as "a system for generating three-dimensional objects by making a cross-sectional pattern of the object to be formed". This means that any 3D object generated using 3D drawing software is first split into layers and these layers are then successively printed by the machine on top if one another. Step one of 3D printing is the generation of a 3D printable model. This model is generated using a computer aided design software or via a 3D scanner. A real life object can be set to be 3D printed by scanning it to get a 3D model that is realistically within the bounds of the 3D printer's capability. Then the STL file is generated by running the design through converting software. You can customize various aspects of the design such as the layer thickness, temperature, and outer finish, etc. Once the STL file is generated, then the object is ready to be printed. After the designing step comes the printing part.

The converted STL file is fed into the printer and according to the layers we have obtained, the machine starts out laying the plastic out layer by layer. The material need not be plastic but it can be anything ranging from liquid, powder, paper or sheet material. The layers are automatically fused to get the final shape. Its advantage over conventional machining techniques is that it can be used to create almost any geometric shape. The object may take anywhere from several minutes to several hours to complete depending on the size and complexity of the model and also on the type of machine used. Some additive manufacturing techniques are capable of using multiple materials to construct parts. They can also use multiple color combinations simultaneously. In case there are projecting parts in the model, supports are used like scaffolding until the overhanging part sufficiently hardens. These supports can be dissolved in water when the model is printed or scaled them out is done in case of 3d metal printing.

2. 3-D PRINTING METHODOLOGY

Selective laser sintering (SLS): This builds objects by using a laser to selectively use together successive layers of a cocktail of powdered wax, ceramic, metal, nylon or one of a range of other materials.

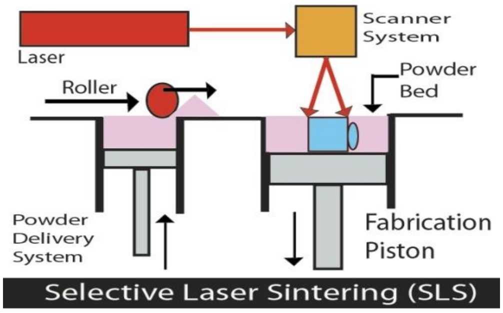

Fig -1: Selective Laser Sintering

3. 3D-METAL PRINTER DETAILS

The Renishaw AM 400 is the latest development of the Renishaw AM platform. Includes larger safe change filter, improved optical control software, revised gas flow and window protection system and a new 400 W optical system to give a reduced beam diameter of 70 µm, in line with the current AM 250 200 W platform. The advantage offered by the AM 400 is the possibility to develop parameters that deliver higher productivity through faster scan speeds, whilst still maintaining feature definition and precision.. The increased laser power of 400 W focused at 70 µm also provides the potential to process materials with elevated melting temperatures, with a significant increase in energy density compared to the current AM 250 400 W system. Build complex metal components direct from 3D CAD data, Transferable parameters from AM 250 200 W to AM 400 systems, Flexible and rapid material changeover, Class leading patented inert atmosphere generation and low argon consumption, Open access material parameter editing, Soft re-coater blade suited to lattice and delicate geometries Build removal via chamber glove box enhances safety.

4. SOFTWARE DETAILS

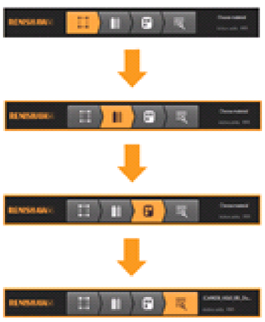

Fig -2: Steps in Additive Manufacturing

STEPS INVOLVED IN ADDITIVE MANUFACTURING SOFTWARE:

A) Orientation – set the angle of the component relative to the build plate.

B) Support – apply sacrificial material to support the component on the build plate.

C) Layout – rapidly arrange your components on the build plate to optimize space.

D) Slice – generate the machine code and directly view scan paths.

KEY FEATURES:

A) .STL geometry import.

B) Part orientation.

C) Add support structures.

D) Material development module with .CSV data import for materials development arrays.

E) Copy and edit material files.

F) Duplicate, orientate and position multiple parts.

G) Rapidly review your geometry and laser tool path slice-by-slice.

H) Review discrete laser exposures within each slice.

5. CONVENTIONAL MANUFACTURING.

MACHINES: Complete manufacturing and polishing of blade is carried out using the below mentioned machines.

Fig -3: 4-Axis CNC Machine HAAS Make

Fig -4: Final Product

6. 3D MANUFACTURING.

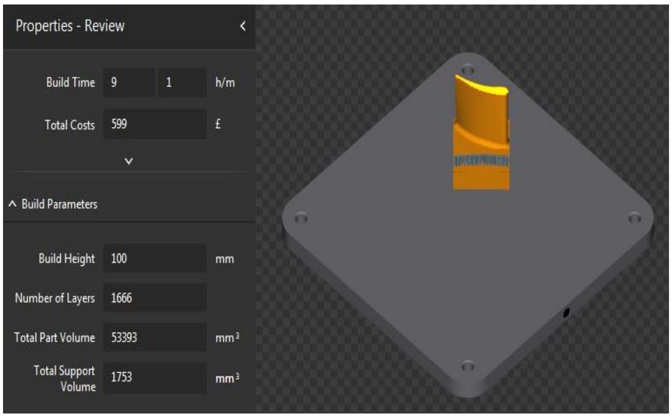

Fig -5: CAD file supports and orientation defined

Fig -6: Final Product of 3D Printing

7. PROCESS PLANNING IN CONVENTIONAL MANUFACTURING

CASE (1) NEW DESIGN:

CAD Model is designed firstly, next are the tool paths definition in which the tool path is given with the tools and the tool number according to the tool number in the (Automatic Tool Changer) ATC in the CNC Machine Simultaneously the G-M Codes are entered and the program is prepared, according to the Program prepared the component is manufactured finally buffing/polishing is carried out to improve the surface finish of component.

CASE (2) RE-ENGINEERING:

CMM plot points are collected and auto-generated in the CAM Software, further if needed according to the auto-generate output the surface quality is checked with the required Sample, if it is adhering to the output required then next step is approached i.e Generation of CAD Model else edit work is carried out till satisfactory results are obtained once the CAD model is generated next are the tool paths definition in which the tool path is given with the tools and the tool number according to the tool number in the (Automatic Tool Changer) ATC in the CNC Machine Simultaneously the G-M Codes are entered and the program is prepared, according to the Program prepared the component is manufactured finally buffing/polishing is carried out to improve the surface finish of component.

8. PROCESS PLANNING IN 3D PRINTING

CASE (1) NEW DESIGN:

CAD Modeling is first step, this geometry is converted to.stl file and exported to Renishaw AM software where supports are provided on the CAD model the location and density is defined in this step also orientation is defined i.e horizontal or vertical and also the layout is defined in the case of multiple objects manufacturing by additive method finally buffing or polishing is carried out as per surface finish required

CASE (2) RE-ENGINEERING:

CMM plot points are collected and auto-generated in the CAM Software, further if needed according to the auto-generate output the surface quality is checked with the required Sample, if it is adhering to the output required then next step is approached i.e Generation of CAD Model else edit work is carried out till satisfactory results are obtained, CAD Modeling is first step, this geometry is converted to a STL file and exported to Renishaw AM software where supports are provided on the CAD model the location and density is defined in this step also orientation is defined i.e horizontal or vertical and also the layout is defined in the case of multiple objects manufacturing by additive method finally buffing or polishing is carried out as per surface finish required.

9. LEAD TIME FOR MANUFACTURING

Conventional:

Table -1: Lead Time for Manufacturing by Conventional Method

Sr.No	OPERATION	TOOL USED	TIME
1	Milling	Φ 50mm Face Mill	00:20:00
2	Centering		00:10:00
3	Feed mill rough sizing.	Φ 50mm Face Mill	00:26:00
4	End Mill Rough Sizing.	Φ 25mm Cr 0.4	00:08:00
6	Concave Rough.	Φ 16mm Cr 4.0	01:30:00
7	Convex Rough.	Φ 16mm Cr 4.0	01:30:00
8	Ball Aerofoil Finish.	Φ 8mm Cr 0.4	00:57:00
9	Sizing.	Φ 16mm Cr 0.4	00:04:00
10	Sizing.	Φ 8mm Cr 0.4	00:25:00
11	Sizing.	Φ 25mm Cr 0.4	00:02:41
12	Root Rough.	Φ 6mm Cr 1	01:53:36
13	Chamfer.	Φ 12mm FF	00:20:47
14	Root Finish.	Φ 5mm Cr 0.5	00:48:53
15	Chamfer Finish.	Φ 10mm Cr 1	00:10:07
16	Trim Tailstock.	Φ 6mm Cr 1	00:05:00
17	Trim Headstock.	Φ 6mm Cr 1	00:07:00
18	Lacing wire hole.	Φ 5mm Cr1	00:05:00
19	Buffing.		00:30:00
		TOTAL TIME	09:33:04

3-D Printing:

Table -2: Lead Time for Manufacturing by 3D Printing Method

Sr.No	OPERATION	TOOL USED	TIME
1	Additive Manufacturing (DMLS)		09:01:00
2	Bead blasting		00:10:00
		TOTAL TIME	09:11:00

10. MATERIAL REQUIREMENT

A) CONVETIONAL MANUFACTURING:

Weight of block: 2000 gm

Final blade Weight: 515 gm

Material wasted: 2000-515

= 1485 gm

% Of Material utilized: (515/2000)*100

= 25.75 %

% of Material Wasted: (1485/2000)*100

= 74.25 %

B) ADDITIVE MANUFACTURING:

Weight of blade with supports: 437 gm

Blade weight: 423 gm

Material Wasted: 437-423

= 14 gm

% Of Material utilized: (423/437)*100

= 96.79 %

% of Material Wastage: (14/437)*100

= 3.2 %

Result:

Table -3: Material comparison for conventional Vs Additive Mfg

	CONVENTIONAL MANUFACTURING	ADDITIVE MANUFACTURING
Material Used	515 gm	423 gm
Material Wasted	1485 gm	14 gm
% Utilization	25.75	96.79
% Wastage	74.25	3.2

11. GEOMETRY COMPLEXITY:

Shapes or geometry are very complex to manufacture conventionally or even impossible in some cases. Complex forms are usually used as an example to explain why 3D Printing is good solution in such cases as they have capability of manufacturing intricately detailed and complex angles require precise measurements and execution. In some cases, it might be the only way to create the desired object.

COMPLEXITY INVOLVED IN CONVENTIONAL MANUFACTURING:

A) TWISTED BLADE:

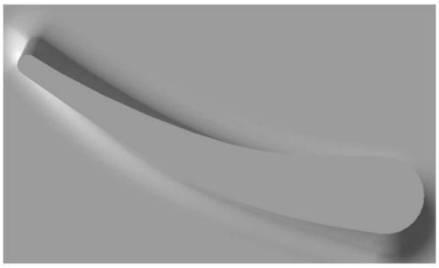

Fig -7: Twisted Blade

B) LACING WIRE HOLE:

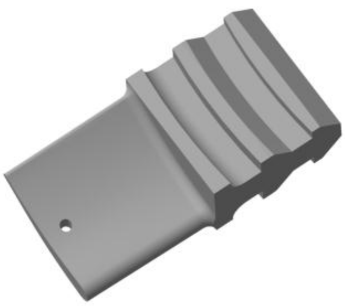

Fig -8: Lacing Wire hole

C) RADIAL SLOT ROOT:

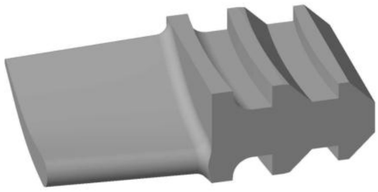

Fig -9: Radial Slot Root

3D-PRINTED BLADE:

A) HOLLOW-ROOT

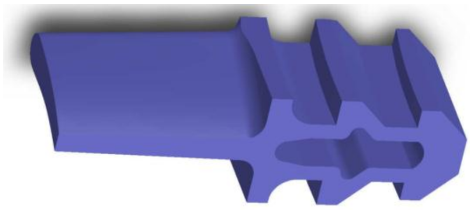

Fig -10: Hollow Root

B) HOLOW BLADE:

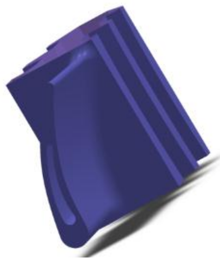

Fig -11: Hollow Root

C) BLADE COOLING:

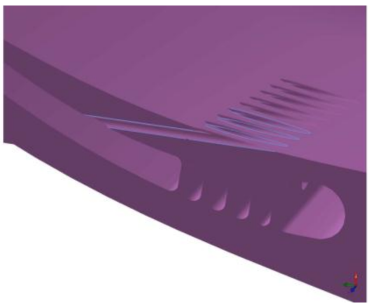

Fig -12: Blade Cooling

D) RIBS INSIDE BLADE:

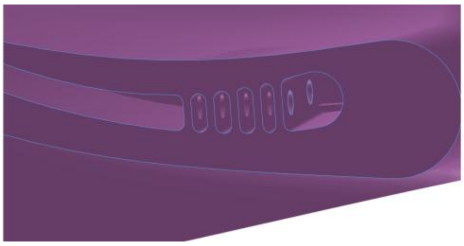

Fig -13: Ribs Inside Blade

E) HOLES ON RIBS:

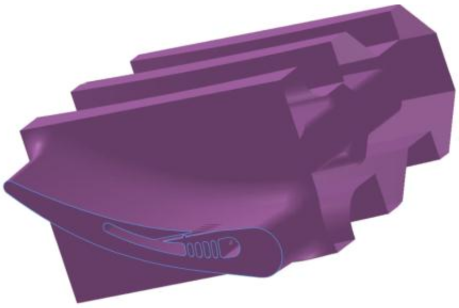

Fig -14: Blade Cooling

12. ENERGY CONSUMPTION:

A) 3-D PRINTING:

Table -4: Energy Consumption for Additive Manufacturing

Sr.No	NAME	CONSUMPTION (KW/Hr)	DURATION (Hr)	TOTAL CONSUMPTION (KW)
1	DMLS	1.8	9	16.2
2	Chiller	2.2	9	19.8
3	Dehumidifier	0.18	9	1.62
4	Sieve	0.8	0.5	0.4
5	Vacuum	1.7	0.5	0.85
			TOTAL	**38.27**

B) CONVENTIONAL MANUFACTURING:

30 H.P Motor – Duration 09:00:00

1 H.P = 745.7 W/Hr

30 H.P = 30 * 745.7 (W/Hr)

= 22.371 KWh

For 9 hours,

9 (Hr) * 22.371 (KWh)

Consumption	201.339 KW

For, Duration 00:33:00

0.55 Hr * 22.371 KWh

Consumption	12.3 KW

For 09:33:00

Consumption	214 KW

Air Compressor: 7.5KWh*9.55

= 71.625KW/Blade

TOTAL CONSUMPTION	285.6 KW

13. CARBON FOOTPRINT

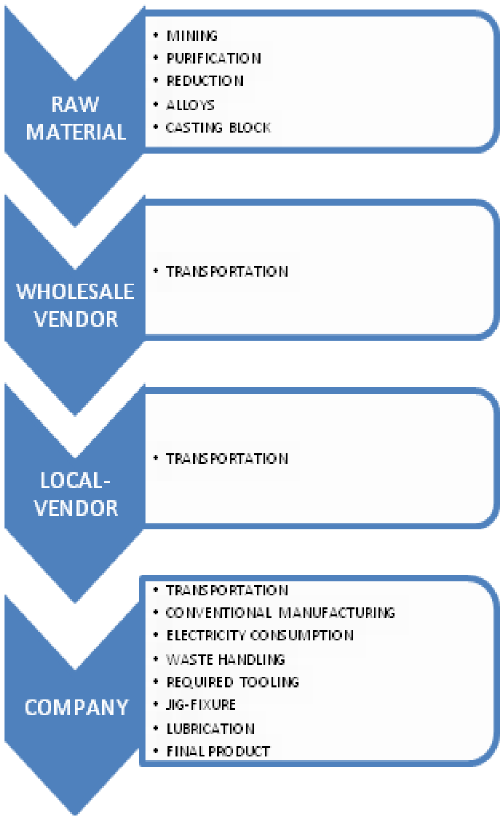

Fig -15: Carbon Footprint in a Conventional process

A) CONVENTIONAL MANUFACTURING:

CARBON FOOTPRINT INVOLVED IN MANUFACTURING:

ENERGY:

30HP Motor requires

(30 * 745.7W) = 22.37 KW

For 1 hr operation the power requirement is 22.37KWh

For 1 blade operation, energy requirement was: 285.6 KW

Electricity Factor = 0.85 kg CO2 per KWh,

Source: CO2 emission factor database, version 06, CEA (Government of India)

68544 (KWh/Yr) X 0.85 (Emission Factor) = 58262.4 (Kg of CO2)/Yr

MATERIAL PROCUREMENT:

HEAD OFFICE to Vadodara (3 trips per year): 2.64 T CO2(e)/ Yr

WASTAGE HANDLING:

6 (Litres/Yr) X 2.653 (Emission Factor) = 15.91(Kg of CO2)

COOLENT/DM WATER:

6 (Litres/Yr) X 2.653 (Emission Factor) = 15.91(Kg of CO2)

TOTAL CO2(e) EMISSION:

= 92.72 T CO2(e)/Yr

B) 3D-PRINTING:

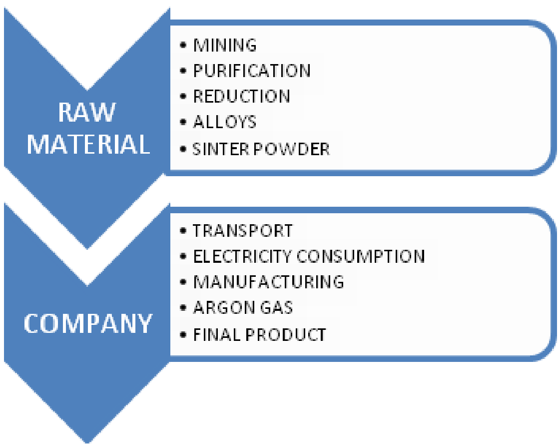

Fig -16: Carbon Footprint in Additive Manufacturing

ENERGY:

38.27KW Power consumption per blade,

38.28 KW * 20 * 12 = 9187.2 KWh/Yr

9187.2 (KWh/Yr) X 0.85 (Emission Factor) = 7809.12 (Kg of CO2)/Yr

MATERIAL PROCUREMENT:

Renishaw (HEAD OFFICE) To Renishaw (Pune) : 5.69 T CO2(e)

WASTAGE HANDLING:

3 (In Liters/Yr) X 2.653 (Emission Factor) = 7.959 (Kg of CO2)

ARGON FILLING:

23 (Liters/Yr) X 2.653 (Emission Factor) = 61.02(Kg of CO2)

TOTAL EMISSION:

= 13.64 T CO2(e)/Yr

If same blade is manufactured for a year, would result in CO2 emissions as mentioned in below table.

Table 5: Results for Carbon emission comparison for Conventional VS Additive Manufacturing:

Table -5: CO2 Emmission

Sr.No	TYPE OF MANUFACTURING	CO2 EMISSIONS/ Yr
1	**Conventional Manufacturing.**	**92.72 T**
2	**3-D Printing.**	**13.64 T**

CONCLUSIONS:

1) LEAD TIME for manufacturing taken is 22 minutes less in 3-D Printing compared to conventional manufacturing.

2) Manufacturing by Conventional method has many steps, energy and time consuming and cannot handle complex manufacturing compared to 3-D Printing.

3) Material wastage in conventional manufacturing is 23.2 times more compared with Additive manufacturing.

4) Material utilization in additive manufacturing is 3.75 times more compared with conventional manufacturing.

5) CO2 Emissions for Conventional manufacturing is 6.8 Times more as compared with 3-D Printing.

6) Energy consumption by CONVENTIONAL MANUFACTURING is 7.5 times more compared to 3-D Printing.

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9) ISSN 2348-1196 (print) International Journal of Computer Science and Information Technology Research ISSN 2348-120X (online) Vol. 2, Issue 2, pp: (378-380), Month: April-June 2014, 3D Printing and Its Applications 1Siddharth Bhandari, 2B Regina 1Student, 2Assistant Professor 12 Dept. of CSE and IT, Saveetha School of Engineering, Saveetha University, Chennai, INDIA

10) A Low-Cost Open-Source Metal 3-D Printer GERALD C. ANZALONE1, CHENLONG ZHANG1, BAS WIJNEN1, PAUL G. SANDERS1, AND JOSHUA M. PEARCE2 1Department of Materials Science and Engineering, Michigan Technological University, Houghton, MI 49931, USA 2Department of Materials Science and Engineering and the Department of Electrical and Computer Engineering, Michigan Technological University, Houghton, MI 49931, USA Corresponding author: G. C. Anzalone (gcanzalo@mtu.edu)

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