Comparison of Infiltration Effect on Selective Laser Sintered Parts

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Abstract-- **Globalization necessitates the rapid launching of new technology in to the market to avoid duplication. Most effective technology to implement this is rapid manufacturing or additive manufacturing, where the parts for produced directly from the CAD data. After the conception of the design, CAD model is created in any of the solid model software and converted into a special file named .stl format. Among various methods of rapid manufacturing, selective laser sintering plays a very vital role in production of near net shaped component. Quality of the rapid prototyping products are decided by the various factors such as process type, type of infiltration, layer thickness, orientation, laser speed etc.,. This paper presents the infiltration effect of various materials produced by selective laser sintered stainless steel green parts. Study of the infiltration effect of copper tin alloy , Brass, and Bronze on stainless steel green part was done. Hardness, dimensional study and surface roughness of different infiltrates were also compared.**

Index Term-- **Selective laser sintering, Infiltration materials, hardness, dimensional study**

1. Introduction

In recent years, the competition of manufactured products has drastically increased. It is more important for new products to reach the market at the earliest possible. Time compression of launching the products from conception, design, prototype, testing and product is very vital [1]. It is possible with the help of computers which can be interacted between all the processes from concept to product [2]. Three stages that lead to the development of rapid prototyping are – manual prototyping is the first phase which took at least four weeks in earlier days. Visual prototype is the second phase where the computers enter into the manufacturing of complex parts that can be simulated, stressed and tested for various mechanical properties. Third phase in prototyping is rapid prototyping where hand prototypes are made in very short time which can be subjected to few testing and can assist in manufacturing.

Rapid prototyping technology is also called as layer manufacturing, additive manufacturing, solid free form manufacturing, direct CADS manufacturing, desktop manufacturing and instant manufacturing as the parts are manufactured by either stacking/joining the parts layer by layer. Basic and common steps involved in all the rapid prototyping technologies are – designing the components on any CAD software and converting into .stl file format. .stl file slices the component design into number of layers depending upon the layer thickness decided. This file is sent to the rapid prototyping machine where the orientation is finalized based upon the shape. Rapid prototyping machine process the file layer by layer where laser rays are used to fuse the metal powders. Selective Laser Sintering (SLS) is the one of the powder based RP technology and most commonly used for the production of both metals and polymer parts. RPT has been implemented in many processes of industry. It allows producing the solid parts at a very rapid rate directly from CAD data. Components can be produced in very short time without the help of tools. Designers can design products without the constraints of manufacturing methods. [1]

The EOS rapid prototyping concept and technology has been discussed in solid free form manufacturing congress. New development in layer manufacturing technology building strategies and materials are reported. Direct sintering of metal powders was discussed. It clearly emphasized the possibility of producing the parts at very faster rate. Continued technical advances in process technology, material and laser with improved integration with preprocess and post processes. [2].

Selective Laser sintering is the most effective and fast growing method of producing parts directly from the CAD data without the usage of tooling. As tooling involves more time and cost, it is difficult to the manufacture the best product at the faster rate in the competitive environment. RPT technologies laid root to produce the parts layer by layer at faster rate with the help of lasers. Laser rays are used for sintering the metal powders. The details of the SLS technique can be found in [3]. For control of the infiltration process, a theoretical model was developed and compared to experimental results. Infiltration model accounts for capillary forces and the pressure difference in the pore. Surface tension and pressure difference in the pore are the most important forces driving the infiltration. For successful infiltration, the infiltration chamber must be slightly above the melting point of infiltrating material.[4]. Parts produced are not dense enough to carry the loads in real applications such as aerospace, moulding tool and biomedical. Hence post processing is necessary to densify the parts. Infiltration is the one of the common methods for densifing the green part produced from SLS machine. The sintered products before and after characterized by their measured density, hardness, bending strength and hardness, results are compared with SEM micrographs to get the infiltration in sintering. Bronze infiltration of laser sintered parts increases the mechanical properties of parts considerably with minimum utilization of energy. Shortage of high laser power density could be overcome by the application of optimized infiltration process as post –processing to the laser sintered product. [5]. Analysis of dimensions, roughness of surfaces, and mechanical properties of the test specimens produced on Object Eden 330 and ZPrinter 310 plus were analyzed. Dimensions of test specimen produced from Oject Eden 330 are more precise than ZPrinter 310. A cyanoacrylate binder features better properties than epoxy resin. By varying process parameters in ZPrinter 310 can reduce the production time. [6]

Layer manufacture (LM) technologies are gaining increasing attention in the manufacturing for the production of polymer mould tooling. A comparison between indirectly SLS and direct SLS to provide the tooling was reported. Build rate, mechanical strength, and accuracy were addressed. Both direct and indirect and indirect SLS can produce the parts with good mechanical properties. Indirect laser is capable of building components at higher rate than direct SLS. The variation in accuracy is limited for both direct and indirect SLS. Good sinterstation process control is required for best results. [7]

Tailoring material properties in parts produced using LM has been demonstrated. Solid model is subdivided into various subparts based on stress analysis. SLS can produce varying mechanical properties by differing the process parameters. Proposed methodology of tailoring the mechanical properties can be used to vary energy density in critical and non critical regions based on FEM analysis. By varying the laser velocity and laser spacing in non critical regions, parts can be built at faster rate. Design of scanning strategy can be utilized in fabricating heterogeneous objects or producing artifacts with desired porosity for fabricating medical implants. Functionally graded parts can also be produced. [8]. Methodology has been designed to archive successful infiltration of indirect selective laser sintered steel components with ferrous alloys with desirable part geometry. Predictive model defined the degree of success of infiltration based on chemical equilibrium to select the temperature of infiltration. It has been observed that equilibrium of solid fraction of the final infiltrated part is at least equal or greater than the brown part solid fraction.[9]

A empirical model have been used to predict the feasibility of different process parameter like laser power, scan spacing, bed temperature, hatch length, and scan count on surface roughness(SR). These factors have been optimized using face centered composite design with response surface methodology. Laser power is most significant parameter which reduces the SR when it increases from middle level (28W) to higher energy (32W). Scan spacing (0.3mm) increases the SR value. Middle level bed temperature (175°C) is best optimal level for minimum SR value with optimal sintering conditions.SR decrease with increase in hatch length. A strong interaction has been observed between laser power, scan spacing, and bed temperature. [10]. Mathematical analysis for the laser energy required for the manufacturing simple components using SLS process. The total energy expended is calculated as a function of total area of sintering (TAS). TAS is correlated to the part geometry, slice thickness and the build orientation. Optimization models have been presented to compute the minimal TAS and laser energy required to manufacture a part using the SLS process. Slice thickness is inversely proportional to the total laser energy for building the part. The methodology developed provides a quick approach to calculate the total laser energy for simple part for any combination of build orientation and build thickness. [11].

Present work analyses the infiltration effect of Brass, Bronze and copper tin alloy. Comparison of surface roughness, hardness and dimensional study was done and analysed.

2. Experiments

2.1 Experimental machine

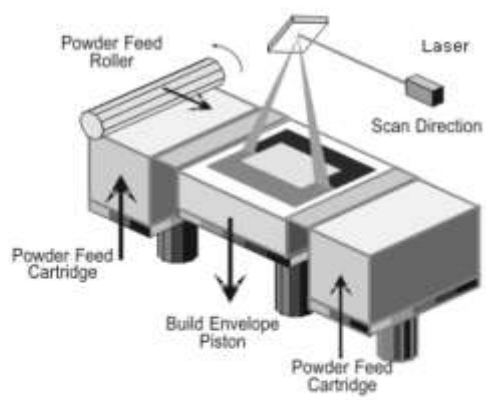


Fig. 1.1 sinterstation 2500 ^{plus} machine and its schematic

Experimental machine used for the production of green part is sinterstation 2500 ^{plus} with build volume of 381^{W} x 330^{D} x 457^{H} mm is shown in fig 1.1. Build step size is 0.10 mm, Hi-Q Thermal control module and Scan speed of 5m/s. Sinterstation 2500 ^{plus} is used to produce the green part of desired CAD design. CAD design is saved as .stl format and sliced in to layers. .stl file is imported to the sinterstation machine. Materials selected for this study are Steel powder ST 100 with Nylon powder as Binder for green part. 50- or 100-Watt CO_2 laser ray is used for fusing the metal and binder. Infiltrants used for post processing are Bronze, Brass and Bell Metal.

2.2. Experimental plan

2.2.1 Green part

Green part is produced in sinterstation machine along with tab which used for infiltration. Stainless steel powder is used as the raw material for manufacturing the green part in sinterstation machine. Fig 2.1 shows the Green Part of Components.

Fig. 2.1 Green Part of Component

Fig. 2.2 Green Part of tab

Stainless steel tabs acts as the gate way for the infiltration of metals or alloys into the stainless steel component. The components and the metals are placed on the tab through which the infiltration process takes place. Thus the tabs must be of the required dimension to accommodate the parts for infiltration. The manufactured tabs are shown n the fig 2.2.

2.2.2. Infiltration

The functional parts or prototypes produced by SLS are not full dense parts. They are weak and unable to withstand the mechanical loads. So green parts produced in SLS requires post processing to densify and strengthen the parts. Infiltration is one of the post processing methods to densify the parts. Selection of infiltrant material will influence the mechanical properties of the part. High density, porous free parts can be fabricated using infiltration technique. This research work is done to find out the effect of infiltration with bronze, brass and copper Tin using a 25 h furnace treatment in a LASER FORM oven (DTM Corporation) with power of 240V AC, 3 phase, 50/60Hz, and 25kV. Oven temperature distribution is shown in fig 2.2.1. Fig. 2.2.2 shows the Laser Form Oven.

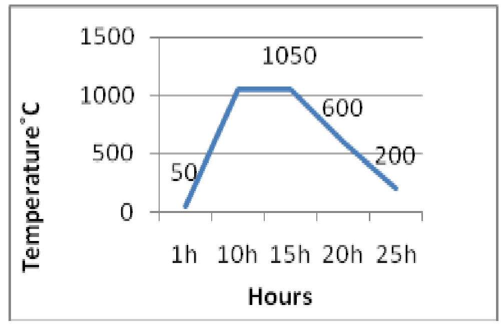


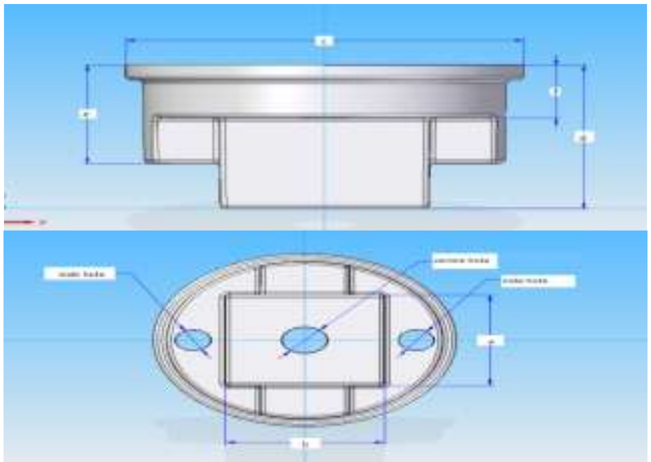
Fig 2.2.1 Oven Temperature Distribution

Fig. 2.2.2 Laser Form Oven

3. RESULT AND ANALYSIS

3.1. Dimensional analysis

The green part obtained consists of network of open pores hence it is fragile in nature. Dimensions are measured using optical profile projector magnification of 20x. Measured values for different infiltrants are tabulated below. Fig 3.21 shows the circular component drawing. Tab 3.1 list out the dimensions .



Dimensions of Circular Component

a	b	c	d	e	f
17.75	18.53	34.50	19.42	13.65	8.29

Tab 3.1 Reference Dimension Of Circular Component

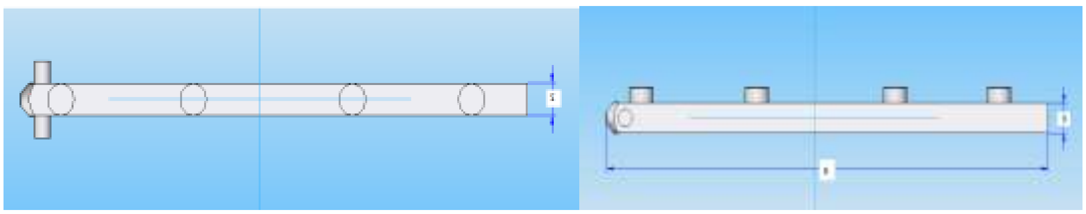


Fig. 3.2 Reference Dimensions of Bar

3.2. Dimension of Sintered Components

Table 3.4 Dimension of Bronze Component

	CAD model (mm)	Green part (mm)	Infiltrated (mm)
X	75	75.35	76.70
Y	10	11.45	12.39
Z	10	10.85	11.52

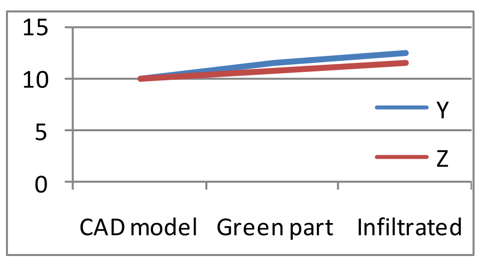


Table 3.5 Dimensions of Brass Component

	CAD model (mm)	Green part (mm)	Infiltrated (mm)
X	75	75.30	76.48
Y	10	11.35	12.30
Z	10	10.80	11.55

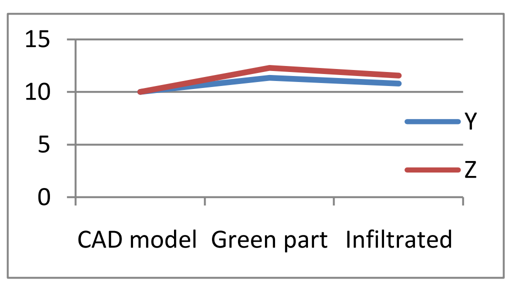
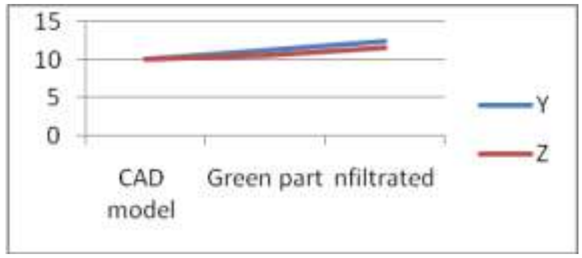


Table 3.4
Dimension of Copper Tin alloy Component

	CAD model (mm)	Green part (mm)	Infiltrated (mm)
X	75	75.25	76.48
Y	10	11.30	12.50
Z	10	10.50	11.60



From the measured values it noticed that the variation in y direction is high compared to other two directions x and z. The effect of type of infiltrants has not much affected the dimensions.

3.3. Brinell Hardness test

Brinell hardness testing machine is used for testing the hardness using 5 mm diameter steel balls. Hardness values are calculated based on the indentation diameter measured and tabulated.

Tab 3.5
Hardness value of Brinell Hardness

S.No	Material	Diameter of the indenter 'D'(mm)	Load 'P' (kg)	Diameter of indentation 'd'(mm)	BHN
1	Brass	5	3000	4.81	74.95
2	Copper Tin alloy	5	3000	4.75	76.65
3	Bronze	5	3000	4.71	85.2

Bronze infiltration has high hardness than brass and Copper Tin alloy. Hence for comparatively high load applications bronze infiltration is suited.

3.4. SURFACE ROUGHNESS TEST

A profilometer SURFCORDER SE1200, Kosaka Lab Ltd., was used to measure the surface roughness. Average surface roughness values (Ra) were determined for each infiltrated components. Average surface roughness values (Ra) in microns are measured. Measurement were made on infiltrated components of different infiltrants and tabulated in tab.3.6. One face of the components was machined using surface grinder and the surface roughness values were noted and tabulated in tab 3.7.

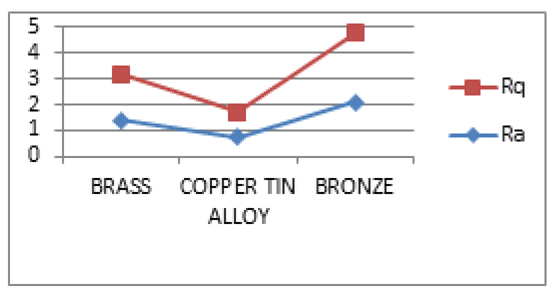


Fig. 3.6 Surface Roughness Values (Before Machining)

Table 3.6
Surface Roughness Values (before Machining)

(µ)	Brass	Copper tin alloy	Bronze
Ra	5.758	3.238	8.102
Rq	7.745	4.647	12.206
Rt	47.688	34.536	84.840
Rp	26.272	17.800	54.720
Rv	21.416	16.736	30.120
Rmax	45.224	33.664	80.648

Table 3.7
Surface Roughness Values (After Machining)

(µ)	Brass	Copper tin alloy	Bronze
Ra	1.406	0.746	2.105
Rq	1.783	0.962	2.652
Rt	10.704	6.884	18.404
Rp	5.516	3.776	9.792
Rv	5.188	3.108	8.612
Rmax	10.704	6.678	18.664

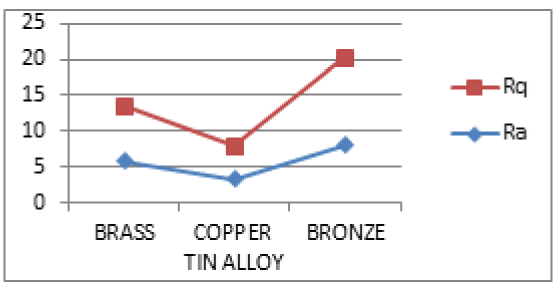


Fig. 3.7 Comparison of Surface Roughness Values (After Machining)

4. Conclusion

Dimensional analysis indicates that deviation from the actual dimension is high in the case of 'y' direction. Hence dimension can be controlled to the actual value by providing the required allowances irrespective of the infiltrants used. Hardness value of bronze infiltrant is high. Bronze can be used for manufacturing of propeller for marine applications and valves. Brass infiltrated components can be used for production of low friction applications. Copper tin alloys can be infiltrated to produce architectural components of any design which is not possible or not economical in conventional process.

References

[1] S. O. Onuh and Y. Y. Yusuf: Rapid prototyping technology: application and benefits for rapid product development. Journal of Intelligent Manufacturing (1999) 10, 301-311.

[2] Udo Behrentdt, Mike Shellbear. The EOS rapid prototyping concept. Computers in Industry28 (1995) 57-61.

[3] Kumar.S. Selective laser sintering – a qualitative and objective approach. JOM 2003:55(10):43-47.

[4] J.Dück, F.Niebling, T.Neeβe, A.Otto Infiltration as post processing of laser sintered metal parts. Powder Technology 145 (2004) 62-68

[5] Kumar.S, Kruth J P. Effect of bronze infiltration into laser sintered metallic parts. Materials and Design 28 (2007) 400 -407

[6] Ana Piliphovic., Pero Raos, Mladen Sercer, Experimental analysis of properties of materials for rapid prototyping . Int J Adv manuf Technol (2009) 40: 105-115

[7] Montasser M.Dewidar, Jay-Kyoo LIM and K.W.Dalgarno,A Comparison between Direct and Indirect laser sintering of metals , J. Mater. Sci. Technol., Vol.24 No.2, (2008)227-232

[8] Prashant K.Jain, Pulak M. Pandey, P.V.M.Rao, Tailoring material properties in layered manufacturing Materials and Design 31 (2010)3490-3498

[9] Phani Vallabhajosyula and David l. Bourell , Modelling and production of fully ferrous components by indirect selectivelaser sintering, Rapid prototyping journal 17/4 (2011) 262-268

[10] Anish sachdeva, Sharanjit singh, Vishal S.Sharma . Investigating surface roughness of parts produced by SLS process Int J Adv manuf Technol (2012)

[11] Ratnadeep Paul, Sam Anand, Process energy analysis and optimization in selective laser sintering, Journal of manufacturing Systems, 31 (2012) 429-437