A Study on the Strength of Sintered Part in SLS Process by Infiltration Technique

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Abstract

Rapid prototyping is the emerging technology to meet the customer needs. A complex profile can be obtained without using any tool and die concepts. Components are produced by Selective Laser Sintering process (SLS) should undergo the process of infiltration with Billets to improve the strength of the component. This paper interconnects these three processes of SLS, regular moulding process and Infiltration process to increase the mechanical properties of the component. Sintered part is produced with ST100 Stainless Steel Powder by SLS Machine. Billets are made by regular moulding processes with various metal powder compositions of Copper, Tin and Zinc. Sintered part and Billets are kept in the oven for infiltration processes for a modified cycle time to increase the mechanical properties of the component. Alumina is playing a vital role to conduct heat through uniformly. Finally infiltrated components were obtained, checked the mechanical properties of surface roughness, surface hardness, tensile strength and microstructure and chemical combination was obtained through EDAX test.

Keywords*: Sintered part, VIT Billets, Infiltration, SLS, Cycle time, Mechanical properties*

1 Introduction

The current day market scenario has changed from the very old product driven market to customer-driven market. Due to increase in global competition, and increase in demands for cost saving, Companies are now forced to look for new technologies for enhancing performance, improving business processes and speed up the product development cycle. In product development, time pressure has been a major factor in determining the direction of the development and success of new methodologies and technologies for enhancing performance. This attributed to emergence of new technologies and the most popular among them is Rapid Prototyping (RP). RP has emerged as a key enabling technology with its ability to shorten product design and development time. Many manufacturing processes are subtractive, in that they modify the geometry of a mass of material by removing parts of the material until the final shape is achieved. (Ex: Conventional milling and turning). An attempt has made in this study to interconnect the three processes namely SLS, regular moulding process and infiltration process to increase the mechanical properties of the components produced.

2 Literature Review

Kruth et al., (2003) have discussed in detail about the various lasers and materials used for selective laser sintering. The quality of laser sintered parts, however, greatly depends on proper selection of the processing parameters. ***Ian Gibson and Dongping Shi (1997*****)** discussed that both powder properties and fabrication parameters have a great influence on the mechanical properties and surface qualities for SLS parts. Powder changes from solid phase to liquid phase and then back to solid phase. ***Mukesh Agarwala et al., (1995)*** discussed about the sintering of metal composites such as Cu-Sn, Cu-Solder, Ni-Sn, pre-alloyed bronze.

Sintering can occur between solid particles by formation of neck between individual particles due to diffusion of atoms along the surface, grain boundaries or other paths at elevated temperature. ***Murali et al., (2003)*** have proposed that processing metallic materials, porosity is still a major problem although a number of notable solutions, such as infiltration with low melting point alloys have been proposed. ***Kruth et al., (2003)*** have measured the particle sizes of the various powder mixtures (Fe, Cu, Ni and Fe3P). The addition of Fe3P or Cu3P (lower melting point additive) is favorable in making the process more energy efficient. ***Zhu et al., (2003)*** developed a Cu-based metal powder which consists of high-purity Cu powder and pre-alloyed SCuP metal powder for direct laser sintering applications. Cu-based material system is attractive because of its good thermal conductivity, high electrical conductivity and low cost.

Based on the literature survey, it was found that the feasibility of producing metal parts by direct laser sintering has been studied using different powder systems including

- Single component powders - Pb, Sn, Zn, Cu, Fe, low carbon steel, Inconel 625, steel based powders, stainless steels and high speed steels.
- Two-component powders - Cu-Sn, Fe-Cu, W-Cu, Cu-Sn-Pb, Co-braze, Ti-6Al-4V, Fe-Sn
- Multi-component powders - Fe/Steel-Cu-Sn, Cu-Sn-Ni-P

Also it was found that improvements in iron and copper based metal powders for laser sintering have a good scope in the future. Proper control over the parameters such as laser power, scan speed, layer thickness, particle size, percentage composition of powder constituents, mixing techniques and laser power density will produce a full dense metal part with good surface quality and appreciable mechanical properties.

3 Experimental Procedures

3.1 *Powders*

3 sets of 9 different compositions each set consisting of 3compositions of powders are considered in this study. Set 1 consists of powder1, powder2 and powder 3, Set 2 consists of Powder 4, powder 5 and powder 6 and Set 3 contains powder7, powder8, and powder9 and these powders are used to make VIT Billets of 9 numbers. Cu, Sn, and Zn powders are mixed according to their weight percentage and the powders are melted at a temperature of 1120˚C.The compositions of powders are given in Table 1

Table 1: Powder composition

SET 1				
	Cu	**Sn**	**Z n**	**Total**
Powder 1				
W%	80	13	7	100
Grams	62.62	10.175	5.4792	78.275
Powder 2				
W%	80	7	13	100
Grams	62.60	5.4792	10.175	78.275
Powder 3				
W%	80	10	10	100
Grams	62.62	7.8725	7.8725	78.275
SET 2				
	Cu	**Sn**	**Z n**	**Total**
Powder 4				
W%	85	5	10	100
Grams	66.533	3.9173	7.8275	78.275
Powder 5				
W%	85	10	5	100
Grams	66.533	7.8275	3.9173	78.275
Powder 6				
W%	85	7.5	7.5	100
Grams	66.533	5.8706	5.8706	78.275
SET 3				
	Cu	**Sn**	**Z n**	**Total**
Powder 7				
W%	90	7	10	100
Grams	70.477	2.3482	5.4792	78.275
Powder 8				
W%	90	10	7	100
Grams	70.477	5.4792	2.3482	78.275
Powder 9				
W%	90	5	5	100
Grams	70.477	3.9137	3.9137	78.275

3.2 *Experimental Machine*

Two machines are used to carry out this research work whose descriptions are given in following subsections.

3.2.1 Experimental Machine 1

The experimental machine 1 is Buffale Electric Furnace which is used to make VITBillets. The specification of the furnace is as follows:

Max Temp: 1200˚C, Volt: 230VAC, Cycle: 50, Amp: 15A, Watts: 3.4KW, Phase: 1. 50ml capacity small crucibles are used to melt the powders. Wooden patterns are made with sizes of 20 x 10 x18 mm for VITBillets. Mold cavity is prepared using china clay.

3.2.2 Experimental Machine 2

The experimental machine 2 is a modified commercial machine, DTM Sinterstation 2500, upgraded with 100 W Co2 laser (Wavelength = 10.6µm) having a spot diameter of 600µm on the processing surface. The approximate laser power obtained at the powder bed for experimentation was 50W. The work chamber is supplied with nitrogen to prevent oxidation of powders during laser sintering. The machine works at a slight over pressure to prevent leakage of oxygen into the work chamber during laser sintering. The laser beam is raster over the part bed surface focused by scanning mirrors and the laser energy is modulated so that only the area which corresponds to the cross section of the object is fused. The 2D cross sections are defined by software, which slices the 3D CAD information into layers. New layers of powders are spread from a powder container.

3.3 ***Experimental Plan***

There are the three major steps of the experiment, as given below:

Step 1: Preparation of VIT Billets

Step 2: Preparation of Sintered parts

Step 3: Process of Infiltration

3.3.1 Preparation of VITBillets

Billets are made with Buffale Electric Furnace. The powders are put in small crucibles and these crucibles are kept inside the furnace. Figure 1 shows the small crucible.

Figure 1

Figure 2

The temperature is raised up to 1000˚C. When the temperature is raised to 1100˚C fumes started to come; again temperature is raised to 1120˚C. Now the metal powder has been melted. Same procedure is followed for all the compositions. Figure 2 shows the molten metals poured (VITBillets) in the cavity.

3.3.2 Preparation of sintered parts

The following parameters are used for experimentation; laser power 50 W, scan speed 100mm/s, layer thickness 0.08mm and scan spacing 0.3mm.The selection of parameters are based on the earlier experiments. The spot size of the laser beam at the powder bed surface was 600µm. Porous sintered components are obtained. Figure 3 shows the sintered parts before infiltration.

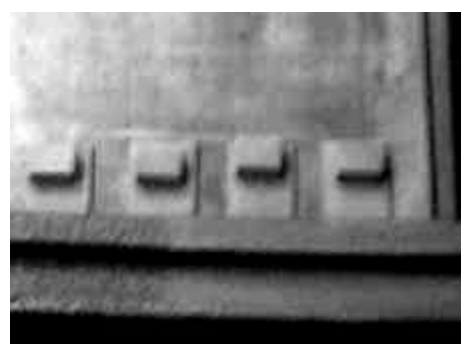

Figure 3

3.3.3 Process of Infiltration

In order to increase the strength of the sintered parts, they are infiltrated with various compositions of VITBillets using 24hrs-furnace treatment in an oven. The cycle is programmed to maintain a temperature of 1070˚C for 6hrs allowing the VITBillets to melt and infiltrate in to the sintered parts. The oven is cooled down to a temperature below 100˚C, while the flow of nitrogen and hydrogen is still continued for maintaining a non-oxidative environment. The modified oven cycle for infiltration has been given in Figure 4.

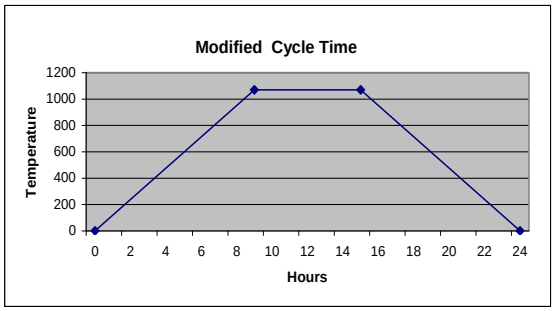

Figure 4

The weight of VITBillets and sintered parts were measured before infiltration. The VITBillets were kept in contact with the porous sintered parts to guarantee infiltration through capillary action. Figure 5 shows the arrangement of VITBillets and sintered parts in the chamber for infiltration process.

Figure 5

4 Results and Discussion

4.1 *Results*

4.1.1 Hardness Measurement

One side of the specimen is grinded and made as a good surface to carry out hardness test along the build direction. Minor load of 10kg is applied on the specimen in order to have contact with steel ball indenter of Ø1.58mm and major load of 90kg is applied on the specimen. 15 seconds of waiting time is given to get the sufficient penetration and the results are summarized in Table 2.

Table 2: Hardness values of the tested specimens (Infiltrated components)

Specimen No	HRB
T1	78
T2	83
T3	81
T4	71
T5	69
T6	64
T7	80
T8	78
T9	74

4.1.2 Surface Roughness

The surface roughness of the specimen (Infiltered component) is measured by scanning along different directions using a Taylor Hobson Form Talysurf roughness meter. A cut off length of 2.5mm is used. The Ra and Rz values measured are shown in Table 3.

Table 3: Surface Roughness values of the tested specimens (Infiltrated components)

Specimen No	Ra in µm	Rz in µm
SET 1		
T1	10.93	60.5
T2	12.42	63.01
T3	8.30	48.59
SET 2		
T4	9.7	53.98
T5	9.35	52.84
T6	11.44	58.04
SET 3		
T7	9.98	49.47
T8	9.21	52.42
T9	11.05	60.76

4.1.3 Measurement of Tensile strength

Micro tensile testing machine is used to measure the tensile strength, proof stress and percentage of elongation and the results are shown in Table 4.

Table 4: Tensile Test Values

Specimen No	Tensile Strength N/Sq.mm	0.2% Proof Stress N/Sq.mm	Elongation %
T1	474	435	3.6
T2	479	440	4.0
T3	524	463	2.8
T4	424	392	2.8
T5	474	425	2.0
T6	424	375	3.6
T7	474	387	4.8
T8	464	415	3.6
T9	50	-	-

4.1.4 Microstructure Study

To study the microstructure of the infiltrated components, the pieces of the specimens are mounted

on phenolic acrylic powder and then the mounted pieces are rubbed with emery sheets varying from grades 320 to 1200. After this diamond polishing is done with the help of diamond polisher and the grinder machine. Etching is done to get the clear view of the microstructure of the pieces. 50% diluted Hydrochloric acid is used as the etchant. The etched components were kept under the microscope and the microstructure is studied under various magnifications like 50x, 200x, 500x, 1000x and the results are shown below (Figure 6 to Figure 14).

Figure 6: (T1)

Figure 7: (T2)

Figure 8: (T3)

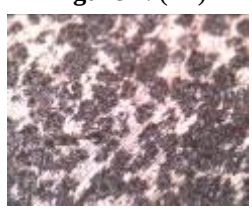

Figure 9: (T4)

Figure 10: (T5)

Figure 11: (T6)

Figure 12: (T7)

Figure 13: (T8)

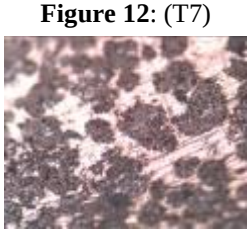

Figure 14: (T9)

4.1.5 Scanning Electron Microscope (SEM) Analysis

Scanning electron microscope (SEM) analysis is done to study the modified structure of the material after the tensile test. The images of the structures are shown below (Figure 15 to Figure 23).

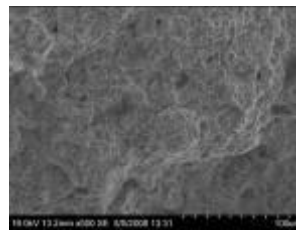

Figure 15: (T1)

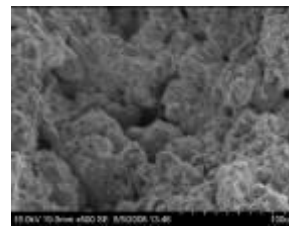

Figure 16: (T2)

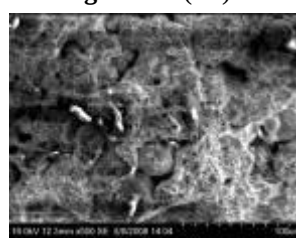

Figure 17: (T3)

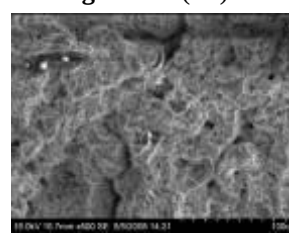

Figure 18: (T4)

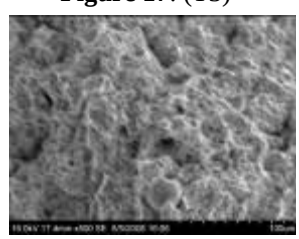

Figure 19: (T5)

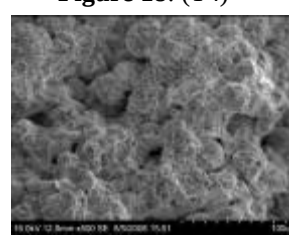

Figure 20: (T6)

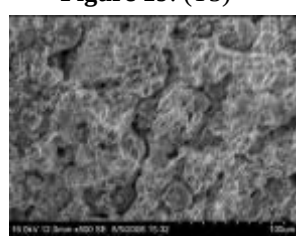

Figure 21: (T7)

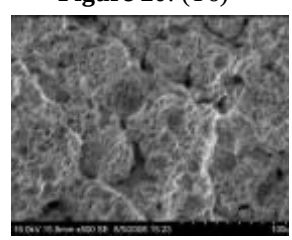

Figure 22: (T8)

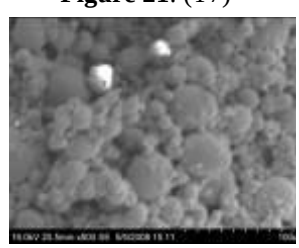

Figure 23: (T9)

4.1.6 Edax Test

EDAX test also conducted to identify the material distribution and the amount of material over a particular area on all the 9 samples and the results are given below.

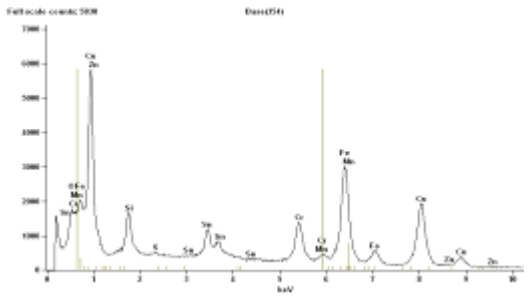

Figure 24: (T1)

Table 5 (T1): Quantitative Results for: Base (354)

Element	Net Counts	Weight %	Atom %
O	4277	2.90	9.85
Si	9074	2.32	4.49
S	2471	0.65	1.10
S	0	---	---
Cr	15513	7.47	7.81
Cr	0	---	---
Mn	2346	1.46	1.45
Mn	20011	---	---
Fe	47646	33.00	32.13
Fe	0	---	---
Cu	33448	46.05	39.40
Cu	0	---	---
Zn	1335	2.56	2.13
Zn	20984	---	---
Sn	7805	3.60	1.65
Sn	0	---	---
Total		100.00	100.00

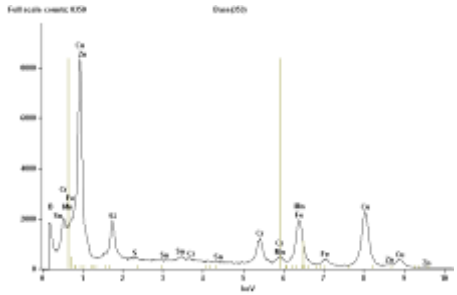

Figure 25: (T2)

Table 6 (T2): Quantitative Results for: Base (353)

Element	Net Counts	Weight %	Atom %
B	9582	64.56	90.96
Si	12243	0.83	0.45
S	2122	0.17	0.08
S	0	---	---
Cr	13037	2.28	0.67
Cr	0	---	---
Mn	5085	1.12	0.31
Mn	0	---	---
Fe	29452	7.23	1.97
Fe	0	---	---
Cu	42274	21.09	5.05
Cu	0	---	---
Zn	2157	1.51	0.35
Zn	26139	---	---
Sn	7733	1.20	0.15
Sn	0	---	---
Total		100.00	100.00

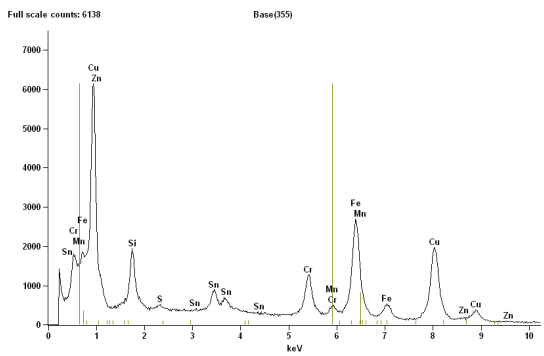

Figure 26: (T3)

Table 7 (T3): Quantitative Results for: Base (355)

Element	Net Counts	Weight %	Atom %
Si	7989	1.91	4.15
S	4113	1.02	1.93
S	0	---	---
Cr	27466	12.98	15.19
Cr	0	---	---
Mn	315	0.19	0.21
Mn	0	---	---
Fe	38948	26.01	28.34
Fe	9157	---	---
Cu	32803	42.54	40.74
Cu	57727	---	---
Zn	2082	3.76	3.50
Zn	0	---	---
Sn	26631	11.59	5.94
Sn	0	---	---
Total		100.00	100.00

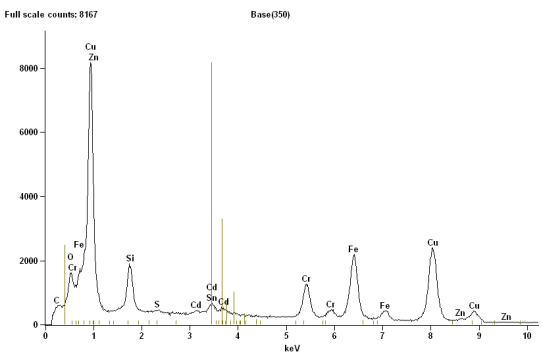

Figure 27: (T4)

Table 8 (T4): Quantitative Results for: Base (350)

Element	Net Counts	Weight %	Atom %
C	3592	13.89	44.13
O	0	0.00	0.00
Si	16521	3.18	4.32
S	1519	0.31	0.36
S	0	---	---
Cr	18851	7.11	5.21
Cr	6405	---	---
Fe	37144	19.59	13.38
Fe	0	---	---
Cu	47435	50.18	30.12
Cu	114287	---	---
Zn	1562	2.31	1.35
Zn	0	---	---
Cd	2562	0.83	0.28
Cd	0	---	---
Sn	7324	2.60	0.83
Sn	0	---	---
Total		100.00	100.00

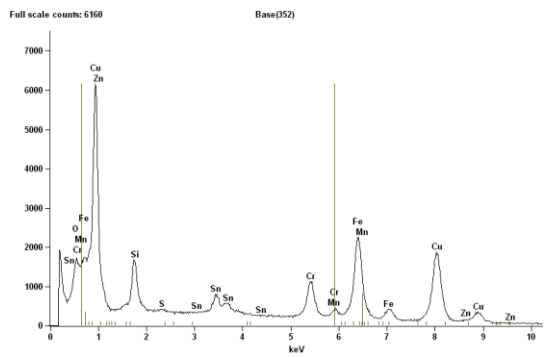

Figure 28: (T5)

Table 9 (T5): Quantitative Results for: Base (352)

Element	Net Counts	Weight %	Atom %
O	10916	7.92	24.59
Si	9960	2.49	4.41
S	1965	0.51	0.79
S	0	---	---
Cr	12641	6.19	5.92
Cr	0	---	---
Mn	2655	1.64	1.49
Mn	0	---	---
Fe	34208	23.47	20.88

Fe	22309	---	---
Cu	34449	46.70	36.52
Cu	28073	---	---
Zn	1181	2.23	1.70
Zn	31403	---	---
Sn	19409	8.84	3.70
Sn	0	---	---
Total		100.00	100.00

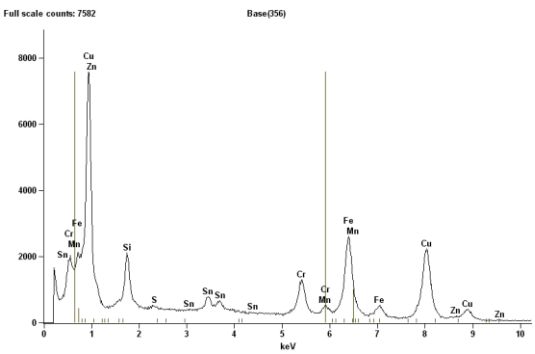

Figure 29: (T6)

Table 10 (T6): Quantitative Results for: Base (356)

Element	Net Counts	Weight %	Atom %
Si	8053	2.11	4.59
S	3675	0.99	1.88
S	0	---	---
Cr	11165	5.59	6.58
Cr	0	---	---
Mn	2496	1.57	1.75
Mn	0	---	---
Fe	34556	24.03	26.35
Fe	46739	---	---
Cu	37582	51.75	49.88
Cu	28778	---	---
Zn	2164	4.15	3.89
Zn	0	---	---
Sn	20973	9.82	5.07
Sn	0	---	---
Total		100.00	100.00

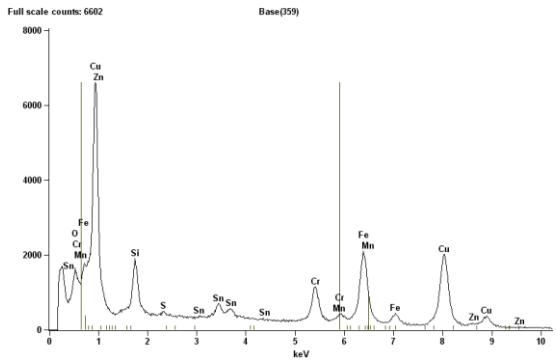

Figure 30: (T7)

Table 11 (T7): Quantitative Results for: Base (359)

Element	Net Counts	Weight %	Atom %
O	0	0.00	0.00
Si	9185	2.75	5.92
S	3055	0.94	1.78
S	0	---	---
Cr	11667	6.69	7.80
Cr	0	---	---
Mn	2446	1.76	1.95
Mn	0	---	---
Fe	28829	23.01	24.94
Fe	0	---	---
Cu	32328	51.04	48.63
Cu	0	---	---
Zn	2125	4.67	4.33
Zn	21183	---	---
Sn	17009	9.13	4.66
Sn	0	---	---
Total		100.00	100.00

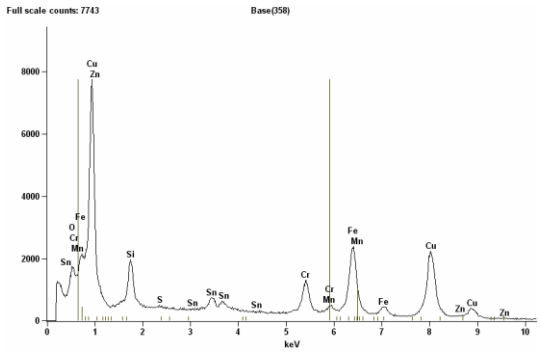

Figure 31: (T8)

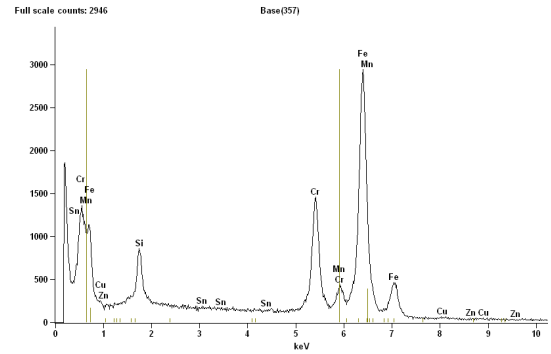

Figure 32: (T9)

Table 12 (T8): Quantitative Results for: Base (358)

Element	Net Counts	Weight %	Atom %
O	1734	1.37	5.04
Si	9946	2.68	5.59
S	2236	0.62	1.13
S	0	---	---
Cr	11472	5.93	6.69
Cr	0	---	---
Mn	2242	1.46	1.56
Mn	0	---	---
Fe	31994	22.98	24.14
Fe	0	---	---
Cu	36523	51.98	47.98
Cu	0	---	---
Zn	1813	3.60	3.23
Zn	21498	---	---
Sn	19416	9.39	4.64
Sn	0	---	---
Total		100.00	100.00

Table 13 (T9): Quantitative Results for: Base (357)

Element	Net Counts	Weight %	Atom %
Si	3984	2.13	4.11
Cr	16503	16.97	17.68
Cr	0	---	---
Mn	3342	4.87	4.80
Mn	22788	---	---
Fe	44599	74.36	72.14
Fe	0	---	---
Cu	389	1.27	1.08
Cu	0	---	---
Zn	0	0.00	0.00
Zn	0	---	---
Sn	401	0.41	0.19
Sn	0	---	---
Total		100.00	100.00

4.2 *Discussions*

The following are the observations of the experiments:

(i) Surface Roughness is better for the components T3 and T8

(ii) Hardness is better for T2 and T3.

(iii) Tensile strength is better for T3 and T2. Elongation wise T7 is the best.

(iv) From Edax test it was found that the infiltration was not uniform. This is analyzed from the material combinations values at the end of the test.

(v) Microstructure study in the optical microscope and the modified structures of the tensile tested components are also studied and the images are obtained

5 Conclusions

It is found that the strength of the hardness specimen is increased by modified cycle time and with more surface contact on tab by making cylindrical groove on the tab. Measured hardness, tensile strength and surface roughness values are higher when compared with the existing materials. Sintering and Infiltration is possible for various compositions of powders. In order to increase the strength of the sintered part infiltration is a must in SLS process. Using of binding materials may increase the surface roughness. This process is applicable in manufacturing of Bearings, Marine castings, hydraulics Valves, Gears, Bullet manufacturing, etc.

References

[1] Abdolreza Simchi, Frank Petzoldt and Haiko Pohl, "Direct Metal Laser Sintering : Material considerations and mechanisms of particle bonding", Solid Freeform Fabrication Proceedings, 2001.

[2] A.N.Chatterjee, Sanjay Kumar, P.Saha, P.K.Mishra and A.Roy Choudhury, "An experimental design approach to selective laser sintering of low carbon steel", Journal of Material Processing Technology, 2003.

[3] B.Van der Schueren and J.P Kruth, "Powder deposition in Selective metal powder sintering", Rapid Prototyping Journal, Vol.1, No.3, 1995.

[4] David L.Bourell, Harris L. Marcus, Joel W.Barlow and Joseph J. Beaman, "Selective Laser sintering of Metals and Ceramics", International Journal of Powder Metallurgy, Vol.28, 1992.

[5] Ian Gibson and Dongping Shi, "Material properties and fabrication parameters in selective laser sintering process," Rapid Prototyping Journal, Vol.3, 1997.

[6] J.P.Kruth, Binding Mechanisms in Selective Laser Sintering and Selective Laser Melting", Solid Freeform Fabrication Proceedings, 2004.

[7] J.P.Kruth, L.Froyen, J.Van Vaerenbergh, P.Mercelis, M.Rombouts, B.Lauwerrs, "Selective laser melting of iron-based powder", Journal of Materials Processing Technology, 2004.

[8] Minlin Zhong, Wenjin Liu, Guoqing Ning, Lin Yang, Yanxia Chen, "Laer direct manufacturing of tungsten nickel collimation component", Journal of Materials Processing Technology, 2004.

[9] Mukesh Agarwala, David Bourell, Joseph Beaman, Harris Marcus and Joel Barlow, "Direct Selective laser sintering of metals," Rapid Prototyping Journal, Vol.1, 1995.

[10] Nikolay K Tolochko, Sergei E. Mozzharov, Igor A.Yadroitsev, Tahar Laoui, Ludo Froyen, Victor I. Titov and Michail B. Ignatiev, "Balling processes during selective laser treatment of powders", Rapid Prototyping Journal,Vol.10, No.2, 2004.

[11] Sanjay Kumar, "Selective Laser Sintering: A Qualitative and Objective Approach", Journal of Material Processing Technology, 2003.

[12] Suman Das, Joseph J. Beaman, Martin and David L. Bourell, "Direct laser freeform fabrication of high performance metal components", Rapid Prototyping Journal, Vol.4, 1998.

[13] Standards International (ISO) : ISO 6508-1 : Metallic materials -- Rockwell hardness test -- Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T) .

[14] Y. Tang, H.T.Loh, Y.S.Wong J.Y.H.Fuh, L.Lu,X.Wang," Direct laser sintering of a copper-based alloy for three-dimensional metal parts", Journal of Material Processing Technology, 2003.

[15] Yongzhong Zhang, Mingzhe Xi, Shiyou Gao, Likai Shi, "Charecterization of laser direct deposited metallic parts", Journal of Materials Processing Technology, 2003.