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INVESTIGATIONS ON THE LUBRICATED WEAR OF DIRECT METAL LASER SINTERED COMPONENTS FOR FUNCTIONAL APPLICATIONS

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ABSTRACT

Direct Metal Laser Sintering(DMLS) is a sequential layered manufacturing method to produce any desired three dimensional parts with simple or complex shapes with no or minimum post-processing. In this study Bronze-Nickel powder was used to make the samples. The samples were produced with the optimized set of parameters such as sintering speed, scan spacing, hatch type, hatch distance and infiltration based on previous studies. To investigate the tribological behavior of the sintered components for functional applications, reciprocating wear tests under lubricated condition were carried out. A ball-on-flat configuration was chosen for the tests. Using Design of Experiments, Taguchi's modified L9 orthogonal Table has been implemented to carry out the experiments. Hardness, load and temperature were the three parameters considered and three levels were chosen for each to create the orthogonal array. Wear tests were carried out with the set parameters and wear rates of the DMLS samples were found out. ANOVA statistical method was used to find the influence of major parameter and the contribution of each parameter on the wear rate of the samples. It has been found that the applied load, one of the selected test parameters had more influence on lubricated wear as compared to other parameters.

Keywords: lubricated wear, DMLS, ANOVA, Taguchi.

INTRODUCTION

Over the years, rapid prototyping (RP) have become popular in new product design and development. Increased concern for the process cost and cycle time, rapid prototyping technology helps in reducing the product development cycle time [1]. RP refers to a technology for quick fabrication of components to net shape without intermediate tooling is recently gaining popularity. Direct Metal Laser Sintering, as an RP technique, consolidates metal powder into a solid component by locally melting and fusing it, the source of concentrated energy being a laser beam. For functional applications of DMLS include fabrication of functional prototypes and Direct Tool, an application for tool making. For the industrial acceptance of DMLS components, significant research and developments have to be made. The mechanical properties of the DMLS components depend on the process parameters by which it is manufactured [2]. Studies related to process optimization are of almost need. The mechanical properties of parts produced by DMLS closely depend on microstructure that can be controlled by the process parameters [3].

For most of the functional products, failure due to wear is considered as a complex one. Abrasive wear mechanism is known to be the prevailing cause of wear in reciprocating components. Coating is suggested to improve hardness and wear resistance of RP components [4]. By controlling the microstructure and mechanical properties, high performance metallic components using DMLS can be produced which can be used directly for functional application [5]. This study concentrates on the effects of load, temperature and hardness on the reciprocating wear testing of DMLS components under lubricated condition. The results of this study aims for a better product which can satisfy functional application.

MATERIALS AND PROCESSING

Materials

DMLS components were manufactured using EOS INT 250 sintering machine using Bronze-Nickel powder by a CO_2 laser. By locally melting the metal powder, the machine consolidates metal powder into a solid component using a concentrated energy source. A wavelength of 10.6 µm and power of 200 W was used for the laser beam. The base powder used is direct metal 50, developed and certified by the Gmbh, Germany. It is a bronze based metal powder with a grain size of 50 microns and a composition of copper 22-90%, tin 2-10%, Nickel 10-70%, Phosphorous 3-6%.

Sintering process

In this study, Nickel is the structural material and Bronze is the binder material. A layer of powder is spread over a base platform and laser beam is passed over it to sinter the required part. During sintering, Nickel particles are bonded together by the bronze particles which will be in a liquid state. This binder fills the voids between the structural particles by capillary action and solidifies on cooling.

Three dimensional model of the component is modeled using 3D CAD software Solidworks. This model is converted into *.STL* file. These files are again sliced accordingly by the RP software and made ready for processing in DMLS machine. The laser beam scans the powder layer as per the CAD data and sinters accordingly. Once the layer of powder is sintered, the building platform moves downward by the selected layer thickness (50 microns). A fresh layer of powder is spread again and the process is repeated till the whole part is built.

Among various parameters sintering speed, hatching type, hatching spacing, post contouring speed

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and infiltration are studied with their corresponding contribution towards wear testing of the specimens. The process parameters were selected using earlier studies which gave the optimized parameters for the manufacture of the components. The optimized process parameters were: Sintering speed: 300 mm/s, Scan Spacing: 0.25 mm/s, Hatch type: Shifted, Post contouring speed: 450 mm/s. Infiltration is also carried out with epoxy resin for the selected components.

Nine test specimens of the size 25x20x15 were manufactured as per the CAD data as shown in Figure-1. EDM wire cutting was used to separate the manufactured components from the base plate. These were machined carefully as per the standards for reciprocating wear testing in lubricated condition following the sintering operation.

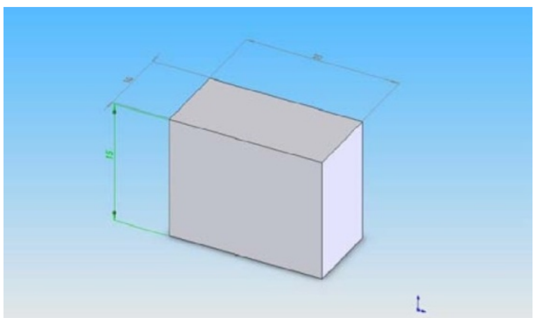

Figure-1. CAD model of test specimen.

The final mechanical polishing was carried out before testing. Surface roughness, hardness and weight of the components were measured before the wear testing. Sintering using DMLS is shown in Figure-2.

Figure-2. Sintering using DMLS machine.

Wear testing

Reciprocating wear testing can be performed under dry conditions or in the presence of lubricants. The machine basically consists of reciprocating arm with a specimen holder on which the ball is fixed and a lower holder for the flat specimen. The ball reciprocates over the flat specimen. Thus wear either occurs to the ball or to the specimen or for both. The values of load to be applied, number of cycles, frequency and cycle time can be set. The data acquisition system in the machine provides the resultant coefficient of friction, temperature, the load applied and the frictional force. A high precision analytical balance is used for measuring the mass of the samples before and after the test. The reciprocating wear test setup is shown in Figure-3.

Figure-3. Wear testing machine.

The samples were cleaned with two solvents. The initial masses of ball and flat samples were noted. The samples were fixed on the machine. The modified orthogonal array is given in Table-1. The parameters were set as given in the Table-2. A commercial grade bearing grease was used as the lubricant. Lubricant was applied at the contact of the specimens and test was carried out as per the standard procedure. The resultant parameters were noted down.

Table-1. Modified L9 orthogonal array.

S. No.	**Hardness** (HV)	**Temperature** (deg C)	**Load** (N)
1	230	50	20
2	230	75	30
3	230	100	50
4	260	50	30
5	260	75	50
6	260	100	20
7	290	50	50
8	290	75	20
9	290	100	30

Table-2. Test parameters.

Parameter	**Frequency** (Hz)	**Stroke length** (mm)	**Duration** (min)
Value	10	15	120

The final mass of the samples were taken. Mass loss was calculated. Wear rate was determined as follows:
Wear volume (mm^3) = Mass loss / Density of the material

Mass Loss (gm) = Initial mass (gm) - Final mass (gm)
Wear rate = Wear volume (mm^3) / sliding distance (m)

Sliding distance = No. of cycles x Stroke length (mm) x 0.002(Conversion factor) = 2160

Table-3. Wear volumes and wear rates of flat samples.

S. No.	**Initial mass** (gram)	**Final mass** (gram)	**Wear loss** (gram)	**Wear volume** (mm^3)	**Wear rate** (mm^3/m)
1	17.6294	17.6263	0.0031	0.4769	2.21E-04
2	17.7314	17.7277	0.0037	0.5692	2.64E-04
3	18.6245	18.6154	0.0091	1.4	6.48E-04
4	18.5909	18.5752	0.0157	2.41	1.12E-03
5	19.4591	19.4483	0.0108	1.66	7.69E-04
6	19.0897	19.0856	0.0014	0.215	9.97E-05
7	18.2218	18.214	0.0078	1.2	5.56E-04
8	19.7446	19.7418	0.0028	0.4307	1.99E-04
9	19.7418	19.7384	0.0034	0.5230	2.42E-04

The calculated values for the nine samples are given in Table-3. Since the focus of the study was to investigate the influence of load, hardness and temperature on the wear of the DMLS components, only the flat samples were considered for further analysis

RESULTS AND DISCUSSIONS

The results were analyzed using Analysis of Variance (ANOVA) statistical method. The contribution of each factor to the wear behavior of components was determined. Average wear rate by each of the test parameters were calculated and are shown in Table-4. The influencing factors with their percentage contribution towards wear rate are tabulated.

Table-4. Wear rate by each factor.

Hardness (HV)	**Average wear rate** (mm^3/m)
230	3.77E-04
260	6.61E-04
290	3.32E-04
Temperature (ºC)	
50	6.31E-04
75	4.10E-04
100	3.30E-04
Load (N)	
20	1.73E-04
30	5.40E-04
50	6.57E-04

The summary of ANOVA for wear results are shown in Table-5. The ANOVA results indicate that each parameter has its own significant contribution on wear. It was found that load has the maximum percentage contribution of 53%. It was followed by hardness with 27% and the least was contributed by temperature with 20%. A graphical representation of the influencing factor on wear testing results is shown in Figure-4.

Table-5. Percentage contributions due to each factor.

Factors	**Hardness**	**Temperature**	**Load**
Sum of quares	1.91E-07	1.45E-07	3.83E-07
Variation due to error	7.20E-07	7.65E-07	5.28E-07
Contribution of factors for cycles	3.59E-07	3.82E-07	2.63E-07
Percentage contribution	27	20	53

Wear rate is found to be higher at higher loads which is in agreement with the results reported earlier. At higher loads, the contact pressures are high leading to higher localized contact temperatures and hence increased plastic flow [6, 7]. By further reducing the load, wear can be limited for a certain functional applications were hardness and temperature are also considered.

Detailed analysis of the surfaces using SEM (Scanning Electron Microscope) and X-ray diffraction techniques are required to investigate the influence of load and hardness on the wear rate.

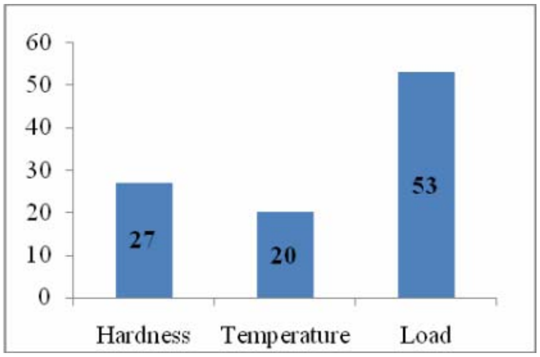

Figure-4. Percentage contribution of factors on wear.

CONCLUSIONS

In this experiment, wear tests were carried out on samples made using DMLS. The most important parameter influencing the wear rate of the DMLS components under lubricated conditions was found out using ANOVA statistical method. It was concluded that load was found to be the most influencing parameter by 53% followed by hardness with 27% and temperature with 20%. The above results were found in accordance to the wear rate values that have been observed. For the same hardness, it was found that the sample tested with the highest load showed more wear. The same was observed when the samples were tested at constant temperatures.

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