Investigations on the Influence of Process Parameters on the Sliding Wear Behavior of Components Produced by Direct Metal Laser Sintering (DMLS)

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***Abstract*—**This work presents the results of a study carried out to determine the sliding wear behavior and its effect on the process parameters of components manufactured by direct metal laser sintering (DMLS). A standard procedure and specimen had been used in the present study to find the wear behavior. Using Taguchi's experimental technique, an orthogonal array of modified L8 had been developed. Sliding wear testing using pin-on-disk machine was carried out and analysis of variance (ANOVA) technique was used to investigate the effect of process parameters and to identify the main process parameter that influences the properties of wear behavior on the DMLS components. It has been found that part orientation, one of the selected process parameter had more influence on wear as compared to other selected process parameters.

***Keywords*—**ANOVA, DMLS, Taguchi, Wear.

I. Introduction

DUE to the increased concern for the process cost and cycle time, the technology is moving towards reduced product life cycles [1]. One way of reducing it is to develop prototypes and analyze them. Rapid prototyping is one of the techniques which are used in the recent days in order to fabricate the prototypes. The different RP processes which are widely used nowadays are stereolithography, selective laser sintering, fusion deposition modeling and direct metal laser sintering etc. Direct Metal Laser Sintering is an additive process for rapid tooling and manufacturing based on laser operations. This technique uses metallic powders in order to develop metallic parts by a process which involves progressive sintering of successive layers of metal powders conforming to the geometry of the successive slice of the CAD models to realize the components with shorter lead time.

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The major advantage of this process is it can use wide range of metal powders such as direct steel, bronze based powder etc. the Cu-based metal powders are also being used for purity and better surface finishing [2]. The major drawback for this process is the surface finish [3] and the wear [4] of the material. An experimental study on the sliding wear behavior of in situ Cu-TiB2 nano-composites fabricated by the reaction of pure titanium and copper-boron on a pin-on-disk wear tester under dry sliding conditions, rubbing against medium carbon steel disk at sliding speed ranging from 0.089 to 0.445 m/s and at loads between 20 N and 140 N. From the experiment it was found that the hardness, yield strength and wear resistance of the composited increased with the content (from 0.5 to 2.5 wt %) of TiB2 nano-particles in the copper matrix [5].

Laser parameters like laser beam power, spot size and experimental parameters like scanning speed and hatching distance have great influence on various properties of laser-sintered bronze product. It is reported that density increases as surface roughness decreases with decrease in hatching distance [6]. It also states about the influence that material parameters like particle size distribution exert on the melting behavior. A reliability study on fatigue strength is reported for test results using components manufactured by DMLS [7]. This paper gives a brief report on the pin-on-disk wear testing and study carried out in order to reduce the sliding wear of DMLS components. These results will be valuable for the functional applications of components [8], for manufacturing of specimens etc. The process parameters such as sintering speed, hatch type, part orientation, infiltration and hatch spacing are considered in this experimental study.

II. Materials and Processing

The components produced by DMLS were carried out on EOSINT M250 laser sintering machine which was developed by EOS Gmbh, Germany. The main advantage of using this technology is the part density and strength. The parts produced are 95% dense. There are no polymer binders that are used in this process. The components are produced directly from the metal powder and hence high accuracy can be expected along with minimal shrinkage. A CO_2 laser is used for this sintering process with the power of 200 W and beam diameter of 0.4 mm. Bronze-nickel powder [9] is used in this process with a grain size of 50 µm. Powder composition is Cu (22-90%), Sn (2-10%), Ni (10-70%), P (0.3-6%). The laser beam melts the metal powder present on the bed and a single layer of the component is formed over the previously sintered layer. The wear plays a major role in the application of the component and hence process parameters with appropriate levels that gives desired values for wear resistance has to be found out.

The process parameters which are considered in order to improve the wear resistance and quality characteristics are sintering speed, hatch spacing, hatch type, part orientation and infiltration. Bonding of metal powder at a temperature slightly above its melting point with the help of a laser source causes sintering process. Sintering speed is defined as the speed with which laser beam sinters. Movement of laser beam takes place in a specified path and with an accurate spacing called as hatch spacing. Scan spacing is generally preferred to be less than the diameter of the laser beam. The pattern in which laser beam moves is known as hatch type. There are two types of hatch patterns that are generally being used in DMLS. One of them are unsorted type, which means that the laser beam moves alternatively in X and Y directions respectively. The other pattern is of shifted type where the laser beam is shifted by half the scan spacing in both X and Y directions. For the first two layers, the pattern is of unsorted type and during the third and fourth layers, the beam shifts by half scan spacing and continues to move as like in the unsorted pattern. The hatch spacing and hatch pattern has a great impact on the heat transfer through powder layer. The orientation of the part either horizontal or vertical i.e. in either X direction or Z direction (0º and 90º) by which the beam moves is called part orientation. In order to increase the density of the component infiltration technique is used. This is normally carried out using epoxy resin. This is done to fill the porous area without affecting the surface finish. For a successful infiltration, the temperature in the infiltration chamber must be slightly above the melting point of the infiltrating liquid.

Design of experiment is the design of any information which has a variation. This can act as an important tool to optimize process parameters where multiple factors are involved. Also, this reduces the product and process variation along with the optimization of the process. In this experiment Taguchi technique [10] was adopted in order to reduce the number of trials. Taguchi method is applied in the early stages of product development for the process to be more effective. This method also enables us to consider various process parameters without much experimentation.

As DMLS is an expensive method, such an orthogonal array has to be selected which has minimum number of trials and hence modified L8 array is considered in this experimental study. In order to find out the effect of process parameters, different levels have to be formulated. Here, sintering speed has four levels varying from 250 mm/s to 550 mm/s with an increment of 100 mm/s. All the other parameters have two levels and vary accordingly. As mentioned earlier, unsorted and shifted are the two types of hatch patterns selected. Hatch spacing selected was 0.2 and 0.4. Part orientation selected was of 00 and 900. Four of the eight specimens manufactured were infiltrated. The developed orthogonal array is shown in Table I.

TABLE I
DEVELOPED MODIFIED L8 ORTHOGONAL TABLE

Trial no.	Sintering Speed (mm/s)	Hatch Spacing (mm)	Hatch Type	Part Orientation (0)	Infiltration
1	250	0.25	unsorted	0	yes
2	250	0.35	shifted	90	no
3	350	0.25	unsorted	90	no
4	350	0.35	shifted	0	yes
5	450	0.25	shifted	90	no
6	450	0.35	unsorted	0	yes
7	550	0.25	shifted	0	yes
8	550	0.35	unsorted	90	no

III. TESTING PROCEDURE

The 3D model of the required component is produced through Solid Works software. The file is then converted into '.stl' format and fed into the machine which automatically converts the file into '.bdf' format using RP Software. The bed surface is properly cleaned and homing is done. The process where the piston moves up and comes down in order for the new layer to be coated is called as homing. The temperature of the fabrication chamber is slightly below the melting point of the metal powder. This is to ensure that the laser beam does not require much energy in order to melt the powder. The process is done by moving the piston up and down and recoating with the powder. Eight different parts are produced for different parameters and they are taken to the EDM cutting machine [11] to remove the final test specimen from the base plate. Infiltration is done for four components where the epoxy resin is first applied on the components and then they are placed in the oven for 3 hours for the equal distribution of heat. Photograph of the wear testing DMLS sample is shown in Fig.1.

Fig. 1 DMLS Wear Testing Specimens

A wide variety of materials including metals, polymers, composites, ceramics, etc can be tested for friction and wear characteristics of dry or lubricated sliding contact using Pin-on-Disc Tester. The test is performed by rotating a counter-face test disc against a stationary test specimen pin. The normal load, rotational speed, and wear track diameter can be adjusted in accordance with ASTM G99 test standard. Wear testing was carried out in the pin on disc wear testing machine as per the standard. Fig. 2 shows the experimental setup of the wear testing machine to find out the wear value of the different DMLS components.

Fig. 2 Experimental Setup for Wear Testing

The speed of the rotating disc was 300 revolutions per minute. The track diameter was 115 mm and the diameter of the rotating disc was 180 mm. The load applied was 3 kg and each component was subjected to wear for 5 minutes .The initial and the final weight of the components was taken. The loss in the weight was found out and tabulated which was further used for calculating the wear rate of the different component. The tabulated value of the wear is shown in Table II.

TABLE II
WEAR CALCULATION OF DMLS SPECIMENS

Specimen No.	Initial Weight (gm)	Final Weight (gm)	Mass Removed (gm)	Wear (mm^3/m)
1	3.9238	3.9233	0.0005	1.08547 E^{-13}
2	3.8797	3.8782	0.0015	3.25641 E^{-13}
3	3.9326	3.9315	0.0011	2.38811 E^{-13}
4	3.8457	3.845	0.0007	1.51965 E^{-13}
5	3.6455	3.6446	0.0009	1.95384 E^{-13}
6	3.3741	3.3728	0.0013	2.82221 E^{-13}
7	3.5465	3.5455	0.001	2.17093 E^{-13}
8	3.5864	3.5846	0.0018	3.90767 E^{-13}

IV. ANALYSIS OF RESULTS

A. Sliding Wear Testing Results

Statistical tool ANOVA was used to analyze the sliding wear results. Contribution of each selected factors on sliding wear of DMLS components were found out. The percentage contribution of influencing factors is shown in Table III. From the analysis it was found that part orientation influences more followed by sintering speed on the sliding wear of DMLS components. Other process parameter does not have much influence on the wear. Specimen 8 has maximum wear as it has large sintering and part orientation is 90^0. Specimen 1 has the least sliding wear due to low sintering speed and 0^0 part built orientation. The components manufactured with a combination of process parameters like lower values of sintering speed and part orientation as 0^0 gives lesser sliding wear. A graphical representation of the influencing factor on the wear testing results is shown in fig. 3.

TABLE III
ANOVA RESULTS

Process Parameter	Sum of Square	F	P	% Contribution
Sintering Speed(mm/s)	0.9237	4.67	0.163	15.55
Hatch Spacing(mm)	0.0236	0.12	0.763	0.397
Hatch Type	0.5891	2.98	0.227	9.92
Orientation	3.9826	0.13	0.046	67.06
Infiltration	0.0236	0.12	0.763	0.397
Error	0.3958			
Total	5.9383			

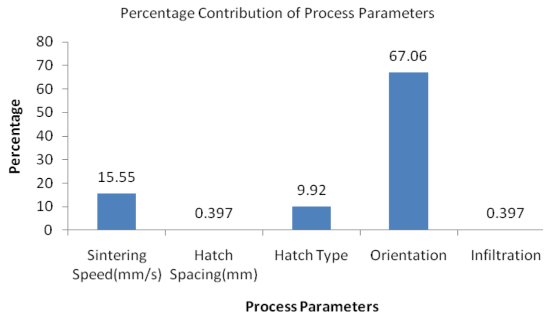

Fig. 3 Percentage Contribution of Factors on Wear

Sliding wear value is lesser for components which are manufactured with 0^0 part orientation. This is because the specimen is loaded perpendicular to the built direction. Particle bonding from layer to layer will be lesser in specimens built with 90^0orientation where loading is parallel to the built direction. Also sintering speed has some influence as the laser moves with lesser speed, better sintering is achieved.

V. CONCLUSIONS

Experiments were carried out to find the influence of process parameter on the sliding wear of components manufactured by direct metal laser sintering using pin on disc wear testing machine. An orthogonal array of modified L8 with different process parameter combination was determined by Taguchi method to optimize the number of experiment. ANOVA analysis shows that part orientation have more influence on the sliding wear as compared to other process parameters. This is because load is applied parallel to the layer built. Results of sliding wear are very much useful to manufacture DMLS components for functional application where these are subjected to sliding wear.

ACKNOWLEDGMENT

The authors wish to acknowledge the support of Department of Science and Technology, Government of India for supporting the project with a research grant. We also thank Central Manufacturing Technology Institute (CMTI), Bangalore for their valuable support to carry out the tests.

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