Effect of Laser Power on Component Strength in Laser Sintering

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Abstract

Prototyping or model making is one of the important steps to finalize a product design. It helps in conceptualization of a design. Before the start of full production a prototype is usually fabricated and tested.
RP processes namely Stereo-lithography (SL), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM) and Laminated Object Manufacturing (LOM) are described.
In Selective Laser Sintering (SLS) process, fine polymeric powder like polystyrene, polycarbonate or polyamide etc. (20 to 100 micrometer diameter) is spread on the substrate using a roller. Before starting CO2 laser scanning for sintering of a slice the temperature of the entire bed is raised just below its melting point by infrared heating in order to minimize thermal distortion (curling) and facilitate fusion to the previous layer. The laser is modulated in such a way that only those grains, which are in direct contact with the beam, are affected. Once laser scanning cures a slice, bed is lowered and powder feed chamber is raised so that a covering of powder can be spread evenly over the build area by counter rotating roller. In this process support structures are not required as the un-sintered powder remains at the places of support structure. It is cleaned away and can be recycled once the model is complete.
This research has examined the effect of Laser power as well as processing parameters on the mechanical properties of selective laser sintered parts from DURAFORM PA
In this research tensile specimens of Polyamide (DURAFORM PA) material as per the test standard 'ASTM D638' are fabricated. This test method covers the determination of the tensile properties of unreinforced and reinforced plastics in the form of standard dumbbell-shaped test specimens when tested under defined conditions of pre-treatment, temperature, humidity, and testing machine speed.
The effects of varying the Laser power, generated by the laser, on the physical and mechanical properties of produced specimens. The energy density is varied by changing the laser power at a fixed value of laser scan spacing. Knowing the relationship between SLS parameter settings and material properties will make it possible to manufacture parts with predetermined properties, customized for various applications.

1. Introduction

1.1Rapid Prototyping

Prototyping or model making is one of the important steps to finalize a product design. It helps in conceptualization of a design. Before the start of full production a prototype is usually fabricated and tested. Manual prototyping by a skilled craftsman has been an age old practice for many centuries. Second phase of prototyping started around mid-1970s, when a soft prototype modeled by 3D curves and surfaces could be stressed in virtual environment, simulated and tested with exact material and other properties. Third and the latest trend of prototyping, i.e., Rapid Prototyping (RP) by layer-by-layer material deposition, started during early 1980s with the enormous growth in Computer Aided Design and Manufacturing (CAD/CAM) technologies when almost unambiguous solid models with knitted information of edges and surfaces could define a product and also manufacture it by CNC machining.

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1.2. Applications of RP Technologies

RP technology has potential to reduce time required from conception to market up to 10-50 percent (Chua and Leong, 2000) as shown in figure 10. It has abilities of enhancing and improving product development while at the same time reducing costs due to major breakthrough in manufacturing (Chua and Leong, 2000). Although poor surface finish, limited strength and accuracy are the limitations of RP models, it can deposit a part of any degree of complexity theoretically. Therefore, RP technologies are successfully used by various industries like aerospace, automotive, jewelry, coin making, tableware, saddletrees, biomedical etc. It is used to fabricate concept models, functional models, patterns for investment and vacuum casting, medical models and models for engineering analysis (Pham and Demov, 2001).

2. Design Of Experiments

2.1. Materials and sample preparation

Materials and Processing

The polyamide (Duraform PA) used in this work as a material was a commercial fine polyamide PA for 3D Systems machine supplied by 3D systems, USA. The density according to ASTM D792 is 1.00[g.cm-3]. Specification sheet for the same is attached for reference.

2.2 Sample preparation

Selective laser sintering (SLS) was performed using a 3D systems Vanguard Sinter station 2000 System to manufacture specimens from DURAFORM PA with a fill laser power (P) of 14, 17, 20, 23, 26, 29 [W], a laser beam speed (BS) of 914 [mm/s], a scan spacing (SCSP) of 0.15 [mm], layer thickness (Lt) of 0.1 [mm], beam diameter (d) of 0.4 [mm] and powder bed temperature (Tb) of 176 [°C].

2.3. Equipment and Methodology

Fig.1: SLS Vanguard 3D Systems Machine

Table 1: Specifications of Machine

Parameters	Value
Model Number	Vanguard (3d systems).
Material	Duraform PA
Scanning speed.	6m/s.
Build speed .	35mm/hr, 1L/hr.
Build volume (mm^3)	381x340x457
Container volume	57 liters.
Laser power/type.	30 W CO_2.
Inert gas.	Nitrogen with 9 LPM.
Layer thickness.	0.08mm, 0.1mm and 0.15mm
Control & part preparation	Sinter/Build Set up.
Software.	
Coolant	Mixture of Distilled water and Glycol.
Input Data File Format	STL
Operating system	Windows XP.

Table 2: Process parameters used in manufacturing test specimens from Duraform PA

Laser power (watts)	14,	17	20	23	26	29
Energy density J/sq.mm	0.073					
Scan speed m/s	914					
Powder bed temp	174					

The process parameters has been given one by one as on from the running machine during the build that was completed in almost four hours of operation.

The snapshots are directly taken from the running software as per the process parameters of the machine. The actual working of the machine can also be seen with the file attached herewith from the videos recorded the machine.

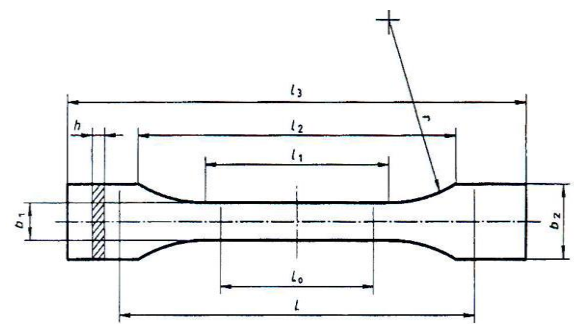

Fig. 2: Shape and dimensions of the tensile test samples

2.4 Tensile curves

The stress-strain curve is a graphical representation of the relationship between stress and strain. The nature of the curve varies from material to material. Stress-strain curves can not only be used to identify some mechanical properties such as Young's modulus, yield strength, fracture strength and elongation at break, but they also allow for making statements and predications about a material's behavior

2.5 Stress calculation

The tensile specimens had a nominal thickness of 3.18 [mm], width of 12 [mm] and other dimensions were determined The sintered specimens were tested under ambient conditions and at a crosshead speed of 1 [mm/min]. The average tensile strength was obtained from three tests. The tensile stress is calculated according to equation

S = *F/A*,

where: s is the tensile stress value in question [MPa]

F is measured force concerned [N]

A is the initial cross- sectional area of the specimen [mm^2].

3. Experimental Methodology

3.1 Tensile curves and Result tables from Universal Testing Machine.

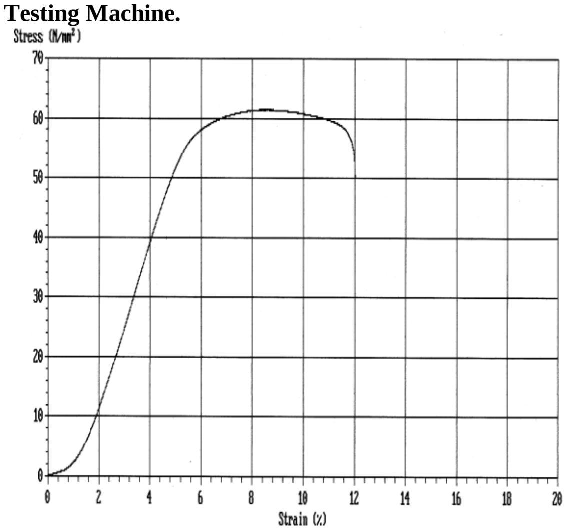

Fig. 3: Sample Set – (Laser Power 14 W)

3.2 Sample Set – (Laser Power 14 W)

Plastic Test Samples by laser - Tensile Test

Plastic Test Samples by laser - Tensile Test

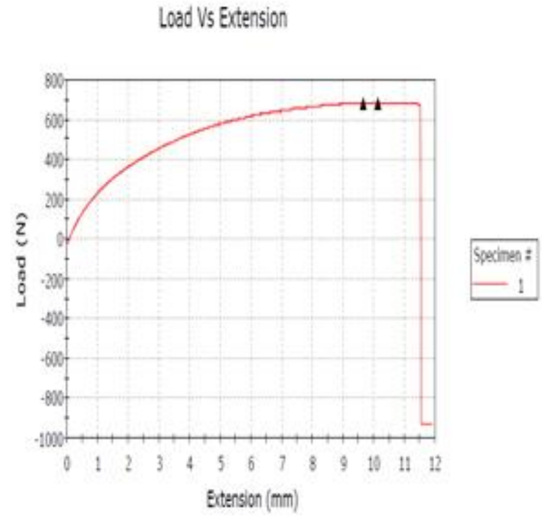

Fig. 4: Mechanical Properties at 14 W, Sample 1

	Load at Tensile Strength (N)	Tensile stress at Tensile Strength (MPa)	Maximum Load (N)
1	682.27993	16.66129	684.94072

	Extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Modulus (E-modulus) (MPa)
1	10.13348	16.72627	97.52063

	Extension at Tensile Strength (mm)	Tensile strain at Tensile Strength (mm/mm)	UYS at YPE/ Ae (Automatic) (MPa)
1	9.66681	0.19334	-----

	UYS or Proof Strength at YPE/ Ae (Automatic) (MPa)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	15.00834	16.72627	0.20267

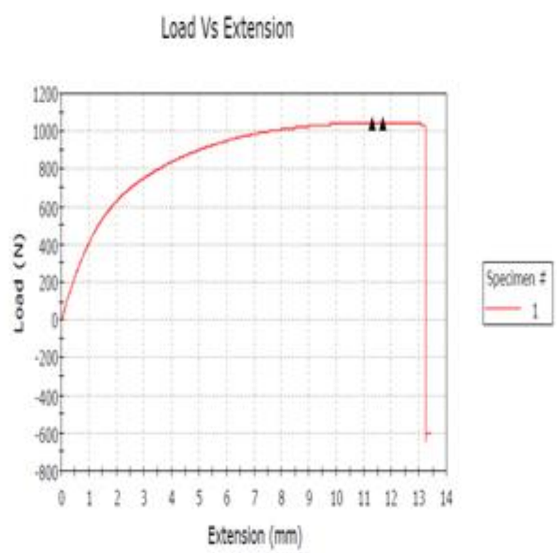

Figure 5: Mechanical Properties at 14 W, Sample 2

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Plastic Test Samples by laser - Tensile Test -

Plastic Test Samples by laser - Tensile Test -

3.3 Sample Set – (Laser Power 17 W)

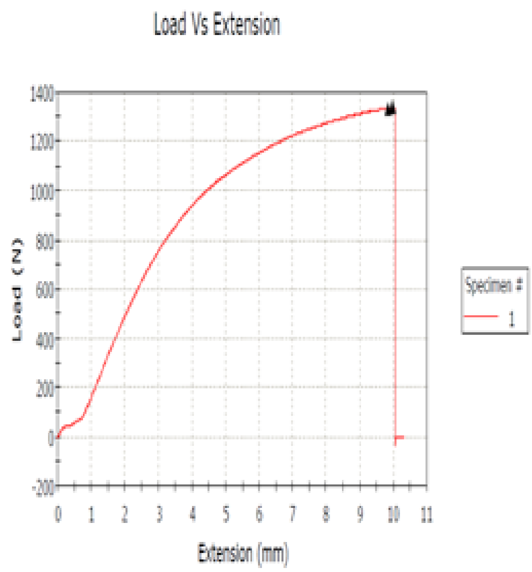

Fig. 6 Mechanical Properties at 17 W, Sample 1

Plastic Test Samples by laser - Tensile Test

Plastic Test Samples by laser - Tensile Test

	Load at Tensile Strength (N)	Tensile stress at Tensile Strength (MPa)	Maximum Load (N)
1	1333.41979	32.56214	1336.10563

	Extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Modulus (E-modulus) (MPa)
1	9.97499	32.62773	362.03554

	Extension at Tensile Strength (mm)	Tensile strain at Tensile Strength (mm/mm)	UYS at YPE/ Ae (Automatic) (MPa)
1	9.85001	0.19700	-----

	UYS or Proof Strength at YPE/ Ae (Automatic) (MPa)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	18.34595	-----	-----

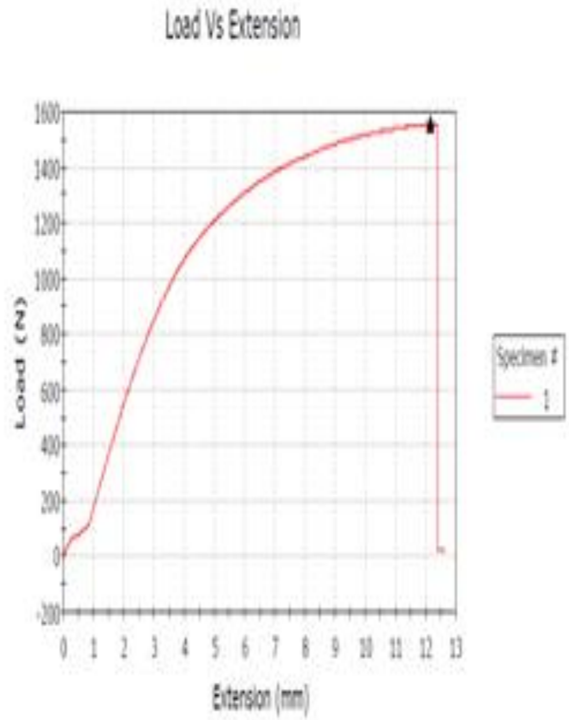

Fig. 7 Mechanical Properties at 17 W, Sample 2

Plastic Test Samples by laser - Tensile Test -

Plastic Test Samples by laser - Tensile Test -

	Load at Tensile Strength (N)	Tensile stress at Tensile Strength (MPa)	Maximum Load (N)
1	1553.32815	37.93231	1554.29654

	Extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Modulus (E-modulus) (MPa)
1	12.14170	37.95596	420.13173

	Extension at Tensile Strength (mm)	Tensile strain at Tensile Strength (mm/mm)	UYS at YPE/ Ae (Automatic) (MPa)
1	12.15830	0.24317	-----

	UYS or Proof Strength at YPE/ Ae (Automatic) (MPa)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	20.26020	37.95596	0.24283

4. Results and discussions.

Tensile testing was done on 18 Samples that were prepared in one go keeping all process parameters of SLS machine apart from the Laser power.

It has been seen in the tabulated results still there are some variations in the strength of the component even among the samples with the same laser wattage

The above point stand correct because even after keeping all the outmost cares in the parameter may it be sample preparation by SLS machine, cleaning by bead blasting or sample testing during the tensile testing, there is always human involvement at every stage which cannot be ignored.

It has also been observed that as we tabulated the results for tensile testing there was no value that would completed with original value 42 MPa of tensile strength as claimed by the supplier of powder, which is 3D systems.

This highest Tensile Strength that was achieved was achieved was on 17 W which is nearly closer to the 13 W as stated in specification sheet of the supplier of DURAFORM PA powder.

Some other parameters that could also be seen in the results as given by machine can also be compared with each other.

If we see the samples that have been broken by universal testing machine, we find that as the wattage of the laser goes up the brittleness also comes in picture.

All the samples that have been tested are given herewith for reference. Laser power independently affects the Tensile Strength of the DURAFORM PA which is a polyamide.

5.1. Conclusions

This work has demonstrated the effect of Laser Power parameters, such on the mechanical properties. The laser power improves the tensile strength, elastic modulus, flexural strength and flexural modulus, up to a certain extent. But the ductility of polyamide with increasing laser power is under the experimental conditions applied. Beside Laser power, Part Bed temperature and other operating parameters covering the SLS process are also important in the mechanical properties and geometric accuracy of polyamide.

Furthermore, this study clearly demonstrated, from higher energy density of the CO2 laser beam results in better fusion of the polymer particles, enabling a more compact structure with a smoother surface to the build.

When the energy density becomes excessively high, however, degradation of the polymer will occur, leading to a slight drop in the density of sintered test parts and blistering of the polymeric material at the surface.

Furthermore the study was also done on used powder that is a mixture of 30% fresh +30% cake and 30% bin powder. This is the actually how the powder is being used in the industrial application to manufacture the components.

Since the powder is costly and is confined to imports only for the respective machines may it be the 3D systems machine or the EOS machines, so it has to be very effectively used for manufacturing of components so as to increase the profitability of the process.

There is very little information from previously published works on the mechanical properties the components which are actually being used in the industry in selective laser sintering process, most of the works has been confined to the laboratories of the academic institutions.

5.2 Future scope and directions of work.

There were some shortcoming in the above study which we felt after the completion of the thesis work may be used as future scope of studies:-

- There is a good scope of study that for how many cycles the powder can be used again and again before being thrown away.
- In the absence of Scanning Electron Microscope (SEM) at our laboratory level, we could not study the microstructures of fusion of powder material and see how well the blending of powder takes place with laser power variation.
- There is surface finish deterioration with the powder being used again instead of fresh or virgin powder, which may be a future scope of study.
- In the similar way a good scope may be on the study of variation in dimensional accuracy of the component through selective laser sintering for the used powders.

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