# Effective Use of Recycled Raw Material in Selective Laser Sintering Process

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***Abstract***

*This paper gives us an overview about the Selective Laser Sintering process. The raw materails that are used in Selective Laser Sintering process. The conventional parameters that are set by the machine manufacturer for using the polyamide raw materials. How large inventories of waste powder are generated due to supplier suggested way of using raw material. How the quality of powder and product is effected with time and recycling and how to use this re-cycled powder effectively to reduce these inventories.*

**Keywords:** *Selective Laser Sintering, Dura Form PA, Tensile testing, etc..*

## I. INTRODUCTION

The study is focused on Selective Laser Sintering, using DuraForm TM Polyamide powder. During prototype building, approximately 4-10% of the powder is used as sintered material and the remainder of the unused powder is recycled (mixed and sieved). Recycling DuraForm Polyamide powder involves mixing 33% fresh powder, 33% used part bin powder and 33% feed bin powder through a sieving station with a 50/70 micron Mesh Screen, as defined by the manufacturer. After 5-7 recycles, this method leads to a powder inventory with inconsistent characteristics that will produce unacceptable models using default machine parameters. It becomes expensive building models over 4 inches high on a consistent basis, considering the amount of powder required for recycling. This method also failed to accurately indicate the number of recycles possible before the powder was unusable.

## II. OBJECTIVE

The main objective of this study was to determine for how many cycles the powder can be used before it is disposed or thrown. We start with fresh PA powder and standard parameters of SLS machine as suggested by the supplier of the machine and carry on with the same machine settings and powder for the entire experiments. We study the effect of used or recycled powder on mechanical and physical properties of the test samples.

## III. APPROACH

A 3D system`s machine sPro 60 HD was used for the Selective laser sintering process. Polyamide (PA12 ) powder was selected as the raw material. Enough fresh powder was filled in the bin so that build could be taken several times. Powder was mixed and sieved after every build cycles. The test specimen were prepared and tested according to ASTM D368 for mechanical and physical properties. Results were analysed for decrease in tensile strength for each cycle to conclude that up to which cycle the powder is usable

## IV. EXPERIMENTAL PROCEDURE

Selective Laser Sintering: In the process of Selective Laser Sintering a build chamber of defined size as per manufacturer is to be filled with powder of required material such as Polyamide with particle size up to 50 μm and a laser scanner unit that generates the X & Y direction. The build chamber is designed such as the movable piston at the bottom gives the Z direction. The whole build chamber and the feed pistons wherein the feed powder is stored is preheated to minimize laser power and completely flooded by shielding gas to prevent oxidation. The laser beam scans each layer. The scan data is obtained from the slice data of each layer and directed by the scanner. The points where beam touches the surface, powder particles are sintered with each other. The temperature is sufficient so that sintering or binding of material takes place. The geometry of the melting spot is defined by the laser beam diameter and the travelling speed. The sintered layer is supported and held stably by the un-sintered powder that surrounds it. While the beam travels further, the molten material solidifies by thermal conductivity into the surrounding powder. Finally, a solid layer is achieved. When one layer solidifies, the piston at the bottom is lowered by the amount of one layer thickness, thus lowering the whole powder cake including the semi-finished part. The space thus created by the lowering of piston is filled with new powder taken from the powder feed chamber using a roller. The roller rotates to its linear movement in order to spread the powder evenly. This is called recoating of powder. After recoating, the build process starts again and processes the next layer. The whole process continues layer by layer until the part is completed.

The part placement in the software is done strategically so as to achieve maximum stability of the product dimensionally and surface finish which is decided by the user before taking the build. After the build is finished and the top layer is added with some more layers of powder so as to give the product even cooling from all side including top, otherwise the product may distort from top thus spoiling the complete build. The cool-down can be done in the machine.

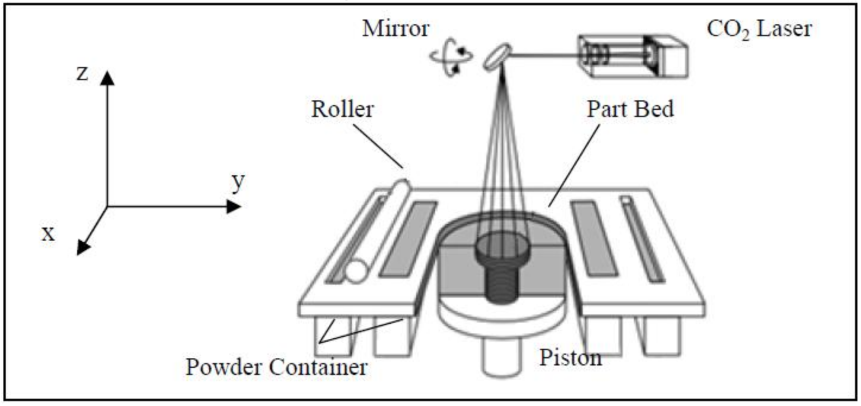

**Figure 1: Layout of SLS machine (Source : Milwaukee School of Engineering)[1]**

## V. MATERIALS USED

The SLS process allows a variety of materials to be used for sintering purpose. Most common among these materials are: polymers, nylons, carbonates, polymer-metal powders, various types of steel alloys. Polycarbonate powders were initially used as starting materials for both experimentation and modelling in the SLS process. in the initial it was found that any material could be combined with another material with a low melting point and acts as an adhesive. INCDMTM researchers tested the use of bonding a protective polymer, commonly used in conventional SLS sintering, thus revealing that a wide range of laser sintered materials can be bonded without protection, which is an advantage compared with other rapid prototyping techniques [3]. It appears that the use of special materials for rapid prototyping is growing and the quality of products is visibly higher. Some of these materials make the SLS process superior to other rapid prototyping techniques, where the material properties depend on the process.

## VI. MACHINE PARAMETERS

The machine available for Selective Laser Sintering is sPro 60 HD model from 3D Systems, USA[7]. SLS 3D printers by 3D Systems produce true, functional thermoplastics with the highest resolution and surface finish of any other SLS process. Following are conventional parameters of machines as per recommendation of supplier :-

- Fill Laser power ---- 17 W.
- Outline Laser Power--- 5.4 W.
- Outline Scan Count---1.
- Slicer Fill scan spacing---0.15
- Roller speed -- 177 mm/sec.
- Part bed temperature--145 deg.
- Feed cylinder temperature--141 deg.
- Part cylinder temperature --140 deg.
- Layer thickness -- 50~ 100 micron adjustable.

**Figure 2 : 3D system sPro 60 HD Laser Sintering Machine.[6]**

### A. *Laser Scanning Strategy*

During the scanning a layer, the laser beam centre does not move all the way to the edge of the layer, but stops before it (Figure 3)[2]. The distance between the centre of the laser beam and the edge of the layer is called the beam offset. In the SLS system, the beam offset can be entered separately for contouring and hatching. In order for the powder at the edge of the boundary to be completely exposed to the laser beam, for the contouring the value of the beam offset, (dc), should be set to the half of the **Dec**. If the beam offset for contour is less or greater than half the effective beam diameter, then there is the possibility of sintering powder outside the layer edge or not sintering part of the intended edge region, which would disrupt the dimensional accuracy of the part. During hatching, the initial beam offset value is again defined with respect to the edge of the boundary (which should be larger than that for contouring), however, in this case caution must be observed in guaranteeing that there are no unsintered particles between the contour path and the hatching region. Thus, the beam offset for hatching (**dh**) must be chosen in such a way, so as to form a narrow overlapping regions between the contour path and the hatching region. The overlap should not bee too wide though, to prevent oversintering.

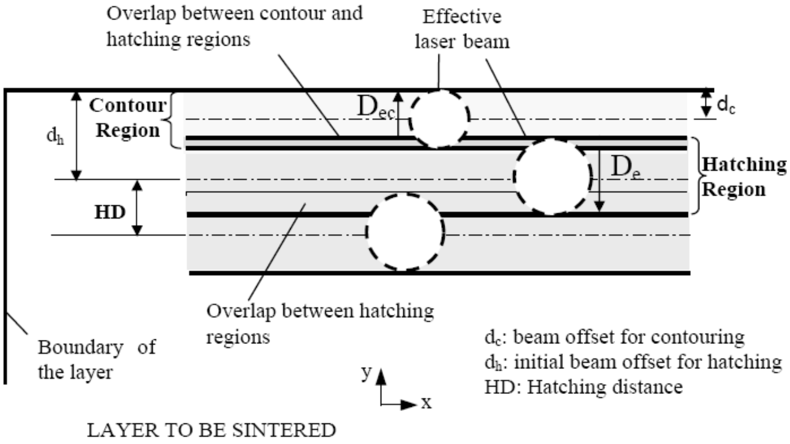

**Figure 3: Beam Offset for Contouring and Hatching and Overlapping Region (Source: The Graduate School of Natural and Applied Sciences)[2]**

## VII.RECYCLING (POWDER MIXING AND SIFTING.)

Previously as per supplier, during model building, a fraction of the powder is used and the remainder of the unused powder is reprocessed (recycled), but in our case no fresh powder is used only remainder of unused powder is recycled again and again.

**Figure 4: Powder Mixing and Sieving Machines**

## VIII. TEST SPECIMEN PREPARATION

Test specimen are prepared starting with fresh powder first and then with recycled powder in a batch of six according to test specimen specifications given in ASTM D 368[4].

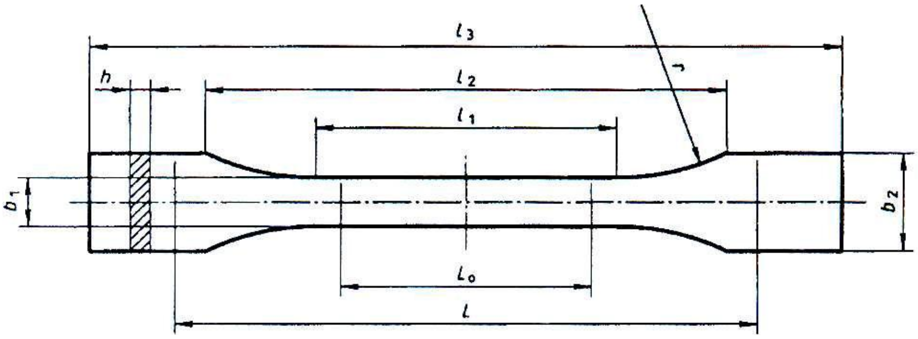

**Figure 5 : Test specimen as per ASTM D368[4]**

| | **Specimen type (ASTM D368)** | **1A** |
|---|---|---|
| *l 1* | Overall length | >150 |
| *L 3* | Length of narrow parallel sides | 80± 2 |
| r | Radius | 20 – 25 |
| l 2 | Distance between broad parallel sides | 104 – 113 |
| b 2 | Width at ends | 20 ± 0.2 |
| b 1 | Width of narrow portions | 10 ± 0.2 |
| h | Preferred thickness | 3 ± 0.2 |
| L 0 | Gauge length | 50 ± 0.2 |
| L | Initial distance between grips | 115 ± 0.2 |

## IX. CLEANING AND FINISHING OF TEST SPECIMEN

### *A. Bead Blasting*

Blasting is the process where small angular or spherical particles are propelled at a part by compressed air, The blast media type, shape, size, density, and hardness, along with media acceleration and volume of media, combined with blasting distance from the work piece, angle of impact and time cycles are important factors in the blast process capabilities.

**Figure 6: Bead Blasting Station and Glass Beads for Test Specimen Cleaning**

Test specimen made in the SLS machine are finished in batches of six each. The finished pieces are further marked with defined number and marking so that to avoid any kind of confusion in the testing done on UTM machine.

## X. MECHANICAL TESTING PROCEDURE

Condition the test specimens at 23 deg C and 50 ± 5 % relative humidity for not less than 40 hrs prior to test in accordance with Procedure A of Practice D 618, unless otherwise specified by contract or the relevant ASTM material specification. Reference pre-test conditioning, to settle disagreements, shall apply tolerances of ± 1 C and ±2 % relative humidity.[4]

Measure the width and thickness of rigid flat specimens with a suitable micrometer to the nearest 0.025 mm (0.001 in.) at several points along their narrow sections. Take the width of this specimen as the distance between the cutting edges of the die in the narrow section. Run the UTM machine and record results as per ASTM D368.

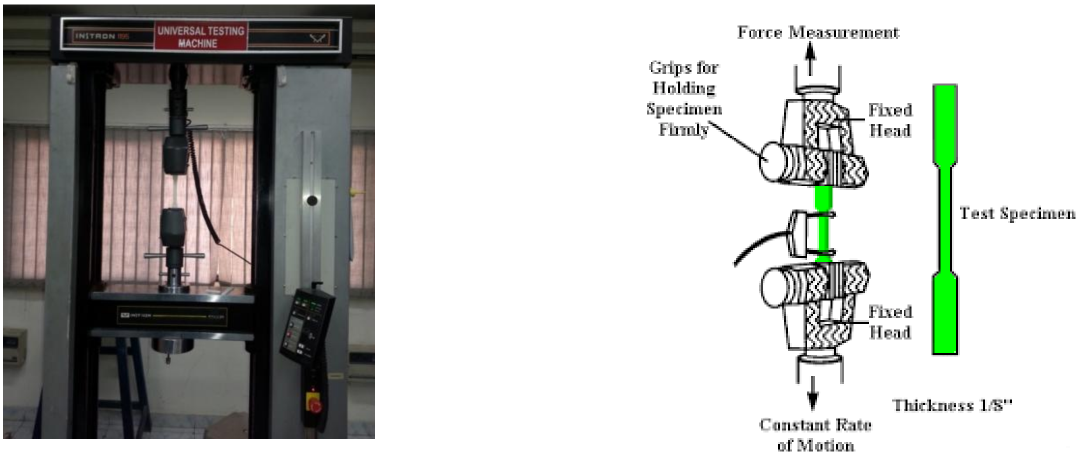

**Figure 7: Universal Tensile Testing Machine and Grips for Tensile Strength Testing**

## XI. RESULTS AND DISCUSSIONS

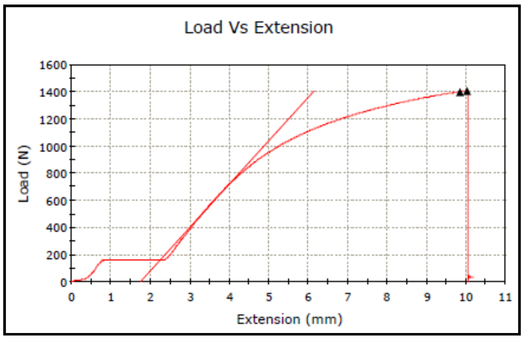

**Figure 8: Load Vs Extension Curve for One of Test Samples**

Test were performed for each set of samples as per ASTM D368 requirement and results were plotted. Tensile testing is conducted and results are tabulated as shown below. We have shown the graph for only the one sample but results are tabulated for all test specimen for the each cycle.

| CYCLE NO. | Sr. No. | Dimension of Test Piece under Test | | | Area of test piece, mm$^2$ | Test Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Width, mm | Thk. mm | Gauge Length, mm | | Gauge Length after break, mm | Max. Load or Breaking Load, N | Tensile Strength, N/mm$^2$ | % Elongation | Tensile Strength, AVG. (N/mm$^2$ |
| CYCLE 1 | A | 12.8 | 3.1 | 50 | 39.68 | 60.25 | 1406.21 | 35.44 | 20.50 | 35.38 |
| | B | 12.8 | 3.1 | 50 | 39.68 | 60.39 | 1410.84 | 35.56 | 20.78 | |
| | C | 12.8 | 3.1 | 50 | 39.68 | 60.06 | 1423.00 | 35.86 | 20.12 | |
| | D | 12.8 | 3.1 | 50 | 39.68 | 59.13 | 1347.24 | 33.95 | 18.26 | |
| | E | 12.8 | 3.1 | 50 | 39.68 | 60.89 | 1432.79 | 36.11 | 21.78 | |
| CYCLE 2 | A | 12.70 | 3.02 | 50 | 38.35 | 60.46 | 1273.04 | 33.19 | 20.92 | 36.01 |
| | B | 12.70 | 3.02 | 50 | 38.35 | 61.25 | 1428.36 | 37.24 | 22.50 | |
| | C | 12.70 | 3.02 | 50 | 38.35 | 61.15 | 1417.73 | 36.96 | 22.30 | |
| | D | 12.70 | 3.02 | 50 | 38.35 | 60.61 | 1380.17 | 35.99 | 21.22 | |
| | E | 12.70 | 3.02 | 50 | 38.35 | 61.97 | 1407.57 | 36.70 | 23.94 | |
| CYCLE 3 | A | 12.80 | 3.00 | 50 | 38.40 | 63.36 | 1387.55 | 36.13 | 26.72 | 35.74 |
| | B | 12.80 | 3.00 | 50 | 38.40 | 62.98 | 1381.57 | 35.98 | 25.96 | |
| | C | 12.80 | 3.00 | 50 | 38.40 | 62.19 | 1356.98 | 35.34 | 24.38 | |
| | D | 12.80 | 3.00 | 50 | 38.40 | 62.21 | 1380.36 | 35.95 | 24.42 | |
| | E | 12.80 | 3.00 | 50 | 38.40 | 61.40 | 1361.96 | 35.47 | 22.80 | |
| | F | 12.80 | 3.00 | 50 | 38.40 | 61.90 | 1365.57 | 35.56 | 23.80 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **CYCLE 4** | **A** | **12.80** | **3.08** | **50** | **39.42** | **64.73** | **1444.45** | **36.64** | **29.46** | 36 |
| | **B** | **12.80** | **3.08** | **50** | **39.42** | **64.93** | **1420.75** | **36.04** | **29.86** | |
| | **C** | **12.80** | **3.08** | **50** | **39.42** | **64.57** | **1388.90** | **35.23** | **29.14** | |
| | **D** | **12.80** | **3.08** | **50** | **39.42** | **63.95** | **1449.39** | **36.76** | **27.90** | |
| | **E** | **12.80** | **3.08** | **50** | **39.42** | **63.39** | **1383.90** | **35.10** | **26.78** | |
| | **F** | **12.80** | **3.08** | **50** | **39.42** | **65.56** | **1427.16** | **36.20** | **31.12** | |
| **CYCLE 5** | **A** | **12.80** | **3.08** | **50** | **39.42** | **66.47** | **1440.47** | **36.54** | **32.94** | 35.45 |
| | **B** | **12.80** | **3.08** | **50** | **39.42** | **65.65** | **1407.82** | **35.71** | **31.30** | |
| | **C** | **12.80** | **3.08** | **50** | **39.42** | **64.21** | **1359.38** | **34.48** | **28.42** | |
| | **D** | **12.80** | **3.08** | **50** | **39.42** | **65.47** | **1384.97** | **35.13** | **30.94** | |
| | **E** | **12.80** | **3.08** | **50** | **39.42** | **66.75** | **1396.40** | **35.42** | **33.50** | |
| **CYCLE 6** | **A** | **12.50** | **3.00** | **50** | **37.50** | **67.59** | **1257.08** | **33.52** | **35.18** | 32.95 |
| | **B** | **12.50** | **3.00** | **50** | **37.50** | **69.02** | **1293.09** | **34.48** | **38.04** | |
| | **C** | **12.50** | **3.00** | **50** | **37.50** | **69.87** | **1236.09** | **32.96** | **39.74** | |
| | **D** | **12.50** | **3.00** | **50** | **37.50** | **67.74** | **1256.98** | **33.52** | **35.48** | |
| | **E** | **12.50** | **3.00** | **50** | **37.50** | **68.42** | **1226.59** | **32.71** | **36.84** | |
| | **F** | **12.50** | **3.00** | **50** | **37.50** | **67.12** | **1143.95** | **30.51** | **34.24** | |

**Table 1 : Cumulative Test Results for All Cycles**

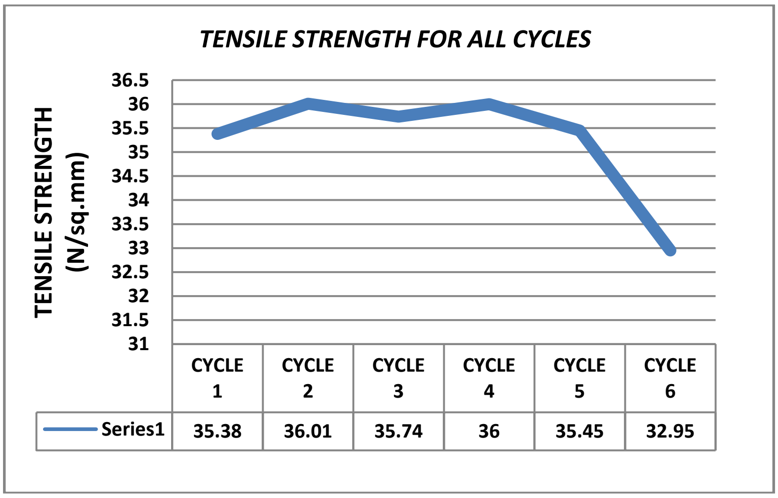

**Figure 9: Graphical Representation for Tensile Strength for All Cycles.**

- As we see from the combined graph of tensile strength it is evident that even after recycling the same powder for five time there was no much drop in the tensile strength of the test specimen.
- When we used the same powder for the sixth time there was a drop of approximately 10% in the tensile strength.
- There was increase in surface roughness on the test specimen after each cycle proceeded.
- So we can conclude that powder can be used effectively after recycling that is mixing and sieving of powder up to five times before being thrown away.

## XII.CONCLUSIONS AND FUTURE SCOPE OF WORK.

- It can be concluded that recycling of powder can be done effectively on after five times and powder is no longer usable after fifth cycle.
- Powder storage can be easily maintained in five different storage bins and inventories can be easily handled.
- Various process parameters can be optimized either by modelling or by a subsequent experimental strategy, so that laser energy transfers to the surface to make the surface more smooth and even build for consecutive cycles.
- Parameters can also be adjusted to anticipate resistance, strength and hardness in a SLS product.

## ACKNOWLEDGEMENTS

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