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Comparative Study on Mechanical Properties of Various Additive Manufacturing Methods

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***Abstract*—This study is mainly focussed to fully understand the mechanical properties and characteristics of the parts manufactured using additive manufacturing. It is very important to understand the mechanical properties of products manufactured through various additive manufacturing processes like Stereolithography (SLA), Selective Laser Sintering (SLS), and Fused Deposition Modeling (FDM) and Polyjet. In this project the mechanical properties such as Dimensional Accuracy, Tensile property and Shore Hardness of components manufactured by various additive manufacturing techniques as per ASTM D638-10 type iv standard are evaluated. Each additive manufacturing process and its process parameters are studied in detail along with comparison of mechanical properties of the final components.**

***Index Terms*—Additive Manufacturing, ASTM D638-10 type iv standard, Dimensional Accuracy, FDM, Polyjet, SLA, SLS, Tensile property, Shore Hardness.**

I. INTRODUCTION

The Additive Manufacturing equipment reads in data from the CAD file and lays downs or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to produce a 3D object, unlike conventional methods, where material is removed to obtain the final object. In this project, the experimental evaluation of mechanical properties such as dimensional accuracy, tensile property and shore hardness on Selective Laser Sintering (SLS), PolyJet, Fused Deposition Modelling (FDM), and Stereolithography (SLA) will be discussed in detail. A set of specimen of three build orientations (horizontal, side, vertical) on each of these additive manufacturing processes according to ASTM D638-10 type iv standards.

II. LITERATURE SURVEY

It is difficult to directly compare the many properties of rapid prototyping parts, as these depend not only on the material being used, but also on the direction in which the property is being measured. In this study, the properties: 1) dimensional accuracy, 2) tensile property, 3) Shore hardness were investigated. According to the previous work and literature source related to these topics, it is observed that the dimensional accuracy of an additive manufacturing product is influenced by a specific rapid prototyping technique used, the material chosen, and the operating parameter values. Due to different processes and materials used in rapid prototyping technologies, parts differ in their tendency to shrink or deform. The accuracy data in this paper was obtained from technical publications and from company literature. There was no comparative information available for different build orientations.

It is observed that the shrinkage of the Stereolithography (SLA) epoxy was significantly less than the Selective laser sintering (SLS) plastic material, and the small shrinkage of Stereolithography (SLA) resins was simple to predict and easy to control. It is observed that the choice of deposition strategy plays an important role in the Fused Deposition Modelling (FDM). Different deposition strategies may cause different performance in mechanical properties.

III. METHODOLOGY

The investigations of dimensional accuracy and tensile properties testing for three build orientations are provided in this paper. Furthermore, Shore hardness for these samples are also available in this study.

A. *Materials and Sample Preparation*

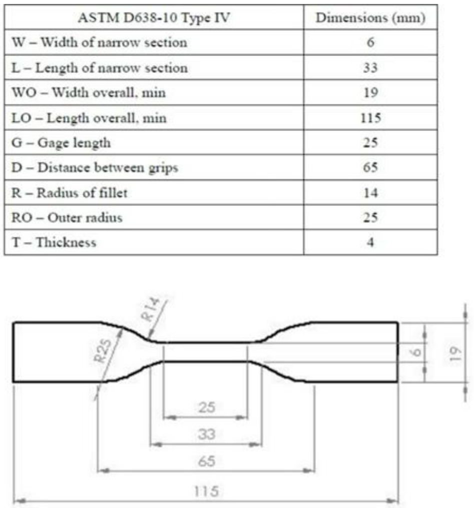
The Table-1, shows the materials and the machine settings that were used in the specified additive manufacturing methods. The materials that were used in this research were the most popular in the current commercial marketplace. The machine settings were also listed in Table I. The test specimens were fabricated by these four additive manufacturing processes in three build orientations as shown in Table I, and the dimensions conformed to ASTM D638-10 Type IV.

TABLE I
MATERIAL AND MACHINE SETTING

System	Material	Machine Setting
SLS	PA 3200 (polyamide 12)	Default Standard calibration for PA3200 Z-Axis = 0.100 mm
Polyjet	Tango Black	Default Print mode = High Quality Z-Axis = 0.016 mm
FDM	ABS plastic	Default Model interior fill = Sparse - High density Support Fill = Sparse Z-Axis = 0.01 inch (0.254 mm)
SLA	ACCURA 60	Default Print mode= Z-Axis = 0.01 inch (0.254 mm)

B. Shape of Test Specimen

The tensile properties of rigid and semi-rigid plastics were determined according to the ASTM D638-10 standard, and the Type IV specimen was used when directly comparing between different rigid materials. Fig 1 presents the dimensions of the tensile test specimen and the location of these dimensions and the shape of the test specimen for tensile testing. The testing speed for the specimen ASTM D638 Type IV is 5 ±25% mm/min, and the higher speeds 50 ±10% mm/min and 500 ±10% mm/min were used, which attains rupture within 1/2 to 5-min testing time.



ASTM D638-10 Type IV	Dimensions (mm)
W – Width of narrow section	6
L – Length of narrow section	33
WO – Width overall, min	19
LO – Length overall, min	115
G – Gage length	25
D – Distance between grips	65
R – Radius of fillet	14
RO – Outer radius	25
T – Thickness	4

Fig. 1. Dimension and shape of test specimen

C. Dimension Measurement

Four ASTM D638 Type IV specimens were made in each of three build orientations (Horizontal, Side, and Vertical). There are four measurement points: width of narrow section (W), width overall (WO), length overall (LO), and thickness (T) on each specimen as shown in Figure 1. Dimension of the specimen was measured by a Pittsburgh digital caliper with the measurement range 0-150/0.01 mm. For the measurement point of width overall, both side on each specimen were measured, and the values were then recorded. For the measurement point of thickness, two ends and middle on each specimen were measured, and then the values were recorded. The average values and standard deviation of each measurement point for specified build orientations and rapid prototyping systems were then calculated.

D. Tensile Property Testing

ASTM Type IV specimens were made in each of three build orientations (Horizontal, Side, and Vertical) in each rapid prototyping systems. Tensile tests were performed on a universal testing machine (ADMET eXpert 2611) equipped with a 10 kN load cell. All the tests were conducted at the same temperature of 72°F.

For determining the tensile properties the test specimen is clamped by the jaws of the test machine and extended with force, at testing speed 5 mm/min as defined by ASTM D638-10 standard. The reported data are the average values from a specimen.

E. Shore Hardness

Horizontal build orientation was chosen to create specimens in the four rapid prototyping systems for investigating the Shore hardness. Two specimens were made in each of the four rapid prototyping systems. Hardness of elastomers and most other polymer materials (Thermoplastics, Thermosets) is measured by the Shore D scale. The durometer, Pacific Transducer Corp. Model 409 ASTM Type D, as shown in Figure 2, was used to measure the Shore hardness. The durometer is a hand-hold device consisting of a needle-like spring-loaded indenter, which is pressed into the test specimen surface, and the penetration of the needle is measured directly from a scale on the device in terms of degrees of hardness. There were six measurement points (three on each side) on each specimen as shown in Figure 3. The measurement was done three times in each measurement point and the average value was then recorded.

Fig. 2. Shore D Scale Durometer

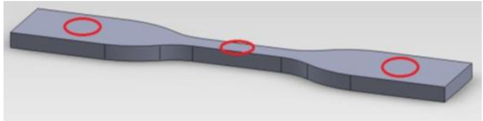


Fig. 3. Measurement Points on Test Specimen

IV. RESULTS AND DISCUSSION

A. Dimensional Accuracy

Dimensional accuracy for each measurement point and each fabricated orientation from specified rapid prototyping systems was also presented in the following sections. Eq. (1), shows how to calculate Dimension Change Rate. Eq. (2) shows Dimensional Accuracy which is the absolute value of dimension change rate from Eq. (2).

$$Dimension\ Change\ Rate\ (percent) = [Measured\ value\ (mm) \,/\, Desired\ value\ (mm) - 1] \times 100 \tag{1}$$

$$Dimensional\ Accuracy\ (percent) = [Measured\ value\ (mm) \,/\, Desired\ value\ (mm) - 1] \times 100. \tag{2}$$

The average dimensional accuracy of four measured points indicates that Vertical build orientation provided the best accuracy (0.6293%) as shown in Figure 4. Vertical build orientation is more accurate in the SLS system.

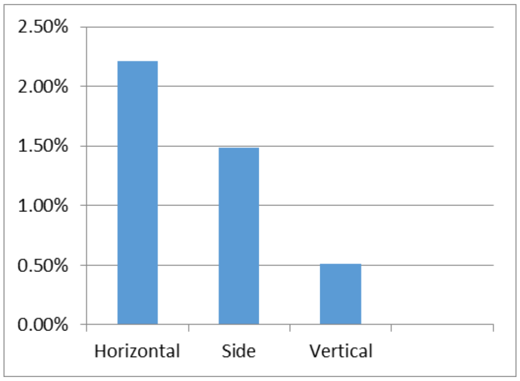


Fig. 4. AVG Dimensional Accuracy of three build orientations in SLS

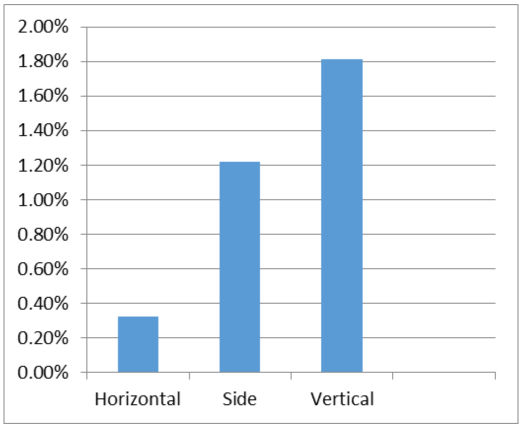


Fig. 5. AVG dimensional Accuracy of three build orientations in Polyjet

The Fig. 5 shows the average dimensional accuracy of three orientations in the PolyJet system. It can be seen that the difference in build orientations results in the different accuracy of specimens. In Fig. 5, the Horizontal build orientation provided more accuracy (0.4257%) than the Side and Vertical orientations for the PolyJet system.

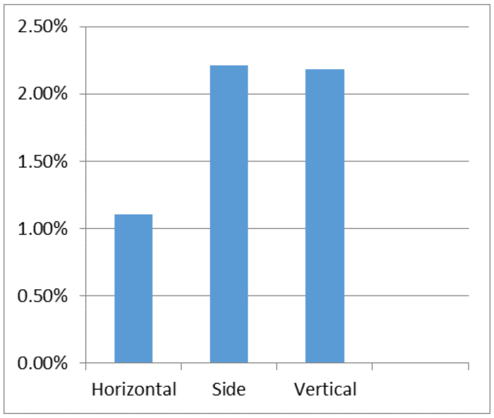


Fig. 6. AVG Dimensional Accuracy of three build orientations in FDM

The Fig. 6, shows the average value of dimensional accuracy in four measured points. It can be seen that the most accurate build orientation appears in the Horizontal orientation. Considering the variation of all measured points, Horizontal also provides less variability as shown in Figure 6. Therefore, we can say that Horizontal build orientation (1.1645%) is more accurate than Side and Vertical in the FDM system.

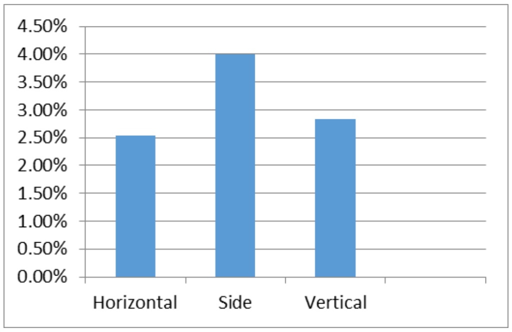


Fig. 7. AVG Dimensional Accuracy of three build orientations in SLA

The Fig. 12, show the average dimensional accuracy of three orientations in SLA. It can be seen that the effect of different build orientations on the dimensional accuracy of the specimens. Considering the variation of four measurement points in Fig. 7 and the average value in Fig. 7, the Horizontal build orientation provided more accuracy than the Side and Vertical orientations in the SLA system.

The Table-2, shows the measured dimensional accuracy percentage values for the additive manufacturing processes.

TABLE II
DIMENSIONAL ACCURACY VALUES

System	Build Orientation	Dimensional Accuracy (%)
SLS	Horizontal	2.2239
	Side	1.5837
	Vertical	0.6293
Polyjet	Horizontal	0.4257
	Side	1.2767
	Vertical	1.7147
FDM	Horizontal	1.1645
	Side	2.3149
	Vertical	2.2445
SLA	Horizontal	2.5702
	Side	3.9541
	Vertical	2.8746

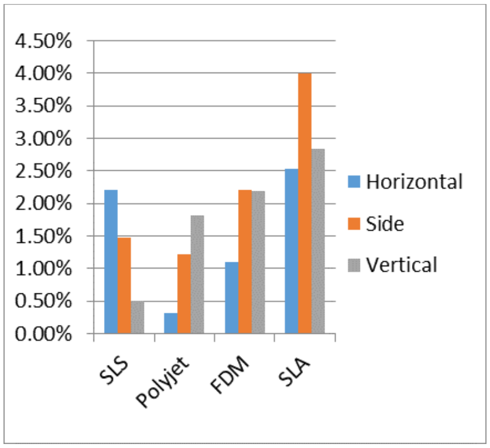


Fig. 8. Dimensional accuracy comparison

B. *Tensile Property*

From the tasks performed, the results obtained from tensile testing are displayed in this section. Test specimens were fabricated with three build orientations (Horizontal, Side and Vertical) in four rapid prototyping machines (SLS, PolyJet, FDM, and SLA). For each type of the specimen, five to eight replications were fabricated and tested. Tensile testing was performed on the specimens using a universal testing machine: ADMET eXpert 2611. The ADMET software was used to calculate the Tensile Strength, Elongation, and Elongation at break of each test sample. For comparisons of tensile testing as a function of direction and method of creation, the bar chart showed in Figure 5 was constructed. Figure 5 displays the average value of the Tensile Strength respectively of the specimens produced under the different rapid prototyping systems and each build orientation.

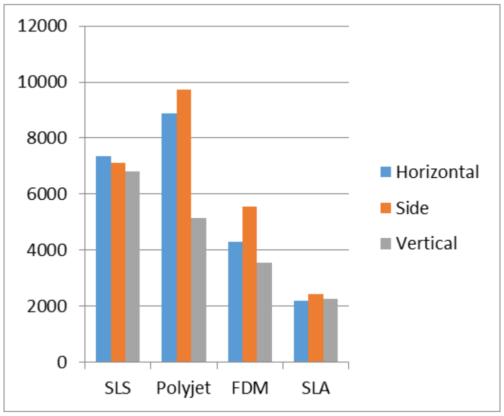


Fig. 9. Tensile strength

It can be seen that the difference in build orientations within the different RP systems does affect the tensile strength of the specimens. Considering effect of using different RP systems, it was found that PolyJet gave the greatest value of tensile strength, followed by SLS, FDM, and SLA, respectively. Considering build orientation, the samples created in Side orientation in PolyJet, FDM, and SLA showed the greatest tensile strength compared with Horizontal and Vertical samples. In the SLS system, the specimens created in Horizontal orientation have the highest tensile strength. Comparing the specimens built in three orientations in the SLS and SLA systems only slightly varied in tensile strength. Comparing Side and Vertical orientations in the PolyJet and FDM systems, a significant difference in tensile strength occurred.

In ASTM D638, the following definition is given: Percent Elongation — Percent elongation is the change in gage length relative to the original specimen gage length, expressed as a percent. Percentage Elongation at Break — Calculate the percentage of elongation at break by reading the extension (change in gage length) at the point of specimen rupture. Divide that extension by the original gage length and multiply it by 100.

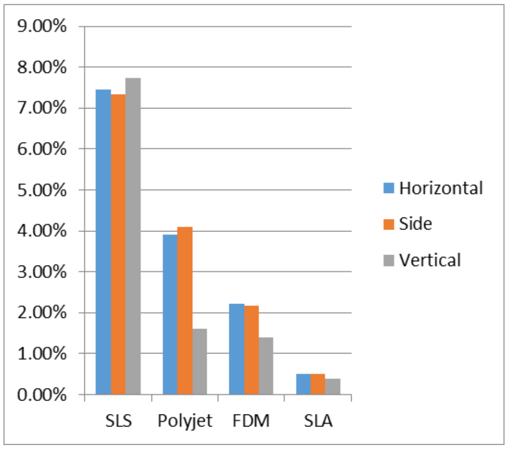


Fig. 10. Elongation (%)

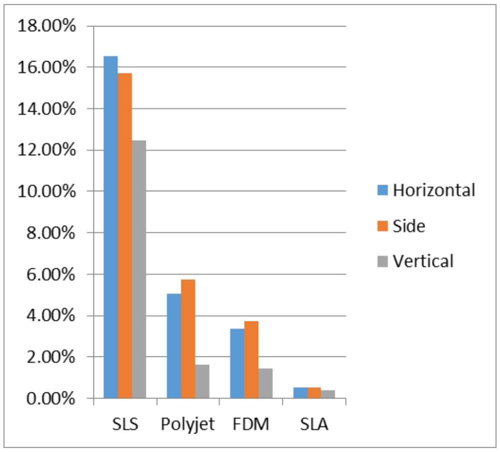


Fig. 11. Elongation at break (%)

Figure 10 and Figure 11 show the Elongation and Elongation at Break, respectively, of the samples produced under the different RP systems and build orientations. It can be seen from the figures that there is a significant difference in Elongation and Elongation at Break between samples produced in SLS and the other three systems. The raw material (PA 3200 Balance 1.0) used in SLS system is based on polyamide 12 which may account for the higher elasticity. However, Elongation and Elongation at Break are different samples created in different orientations in the same RP system.

C. *Shore Hardness*

Hardness of hard elastomers and most other polymer materials (Thermoplastics, Thermosets) is measured by the Shore D scale. The scale resulting in the values between 0 and 100, with higher values indicating a harder material.

Shore hardness is a measure of the resistance of a material to penetration of a spring loaded needle indenter. Two specimens were created in the Horizontal build orientation in each RP system: SLS, PolyJet, FDM, and SLA. The reason to choose Horizontal build orientation was the shortest machine duration compared with Side and Vertical. For the Shore Hardness investigation, the independent variable was the specified rapid prototyping system and its relative material used, and the dependent variable was the Shore Hardness. The independent variable, build orientations, was not included in this investigation. There are three measured points on two long planes; total six measured points in one specimen.

TABLE III
SHORE HARDNESS

System	ASTM D2240 Type D Scale	Standard Deviation
SLS	76.2434	1.7237
Polyjet	83.7365	0.7975
FDM	77.6964	2.2453
SLA	81.4534	1.2978

V. CONCLUSION

Considering different rapid prototyping systems, PolyJet performs with the best dimensional accuracy. Considering the build orientations, Horizontal is more accurate than Side and Vertical in PolyJet, FDM, and SLA, with the exception of the SLS system. In SLS, the Vertical build orientation has more dimensional accuracy than others. Table II tabulates the summary dimensional accuracy in these four rapid prototyping systems.

Considering build orientations, the samples created in Horizontal and Side have a greater Elongation and Elongation at Break in PolyJet and FDM compared with the Vertical orientation. The specimens of vertical build orientation resulted in the lowest Elongation and Elongation at Break because the tensile loads were resisted only by the bonding between layers, and not the layers themselves.

The order of shore hardness is PolyJet > SLA > FDM > SLS. The highest scale of Shore hardness appeared in the test specimens created by PolyJet technology with 83.73, while the lowest scale of Shore hardness can be seen in the samples created by SLS technology with 77.69.

REFERENCES

[1] Chua, C.K., K.F. Leong, and C.S. Lim, Rapid prototyping : principles and applications. 3rd ed2010, Singapore ; Hackensack, NJ: World Scientific.

[2] Peter D. Hilton, P.F.J., Rapid tooling: technologies and industrial applications2000, New York: Marcel Dekker.

[3] Noorani, R., Rapid prototyping : principles and applications2006, Hoboken, N.J.: Wiley. xxi, 377 p.

[4] Kruth, J.P., Material incress manufacturing by rapid prototyping techniques.CIRP Annals-Manufacturing Technology, 1991. 40(2): p. 603-614.

[5] Klocke, F., T. Celiker, and Y.A. Song, Rapid metal tooling.Rapid Prototyping Journal, 1995. 1(3): p. 32-42.

[6] Steve, U. and F. Richard, The rapid prototyping technologies.Assembly Automation, 2003. 23(4): p. 318-330.

[7] Pham, D.T. and R.S. Gault, A comparison of rapid prototyping technologies.International Journal of Machine Tools and Manufacture, 1998. 38(10): p. 1257-1287.

[8] PROTO3000. 3D Printing Advantages. Available from: http://www.proto3000.com/rapid-prototyping.aspx?topidcol=11.

[9] Ibrahim, D., et al., Dimensional error of selective laser sintering, three-dimensional printing and PolyJet models in the reproduction of mandibular anatomy.Journal of cranio-maxillo-facial surgery : official publication of the European Association for Cranio-Maxillo-Facial Surgery, 2009. 37(3): p. 167-173.

[10] Hopkinson, N., R. Hague, and P. Dickens, Rapid manufacturing: an industrial revolution for the digital age2006: Wiley, ISBN: 0-470-01613-2.

[11] Pham, D., &Dimov, S., Rapid manufacturing: the technologies and applications of rapid prototyping and rapid tooling2001, New York: Springer.

[12] Fortus, S. FORTUS FDM Thermoplastics Material Comparison. 2013; Available from: http://www.fortus.com/Materials/FDM-Material-Comparison.aspx.

[13] CustomPartNet. FusedDepositionModeling (FDM). 2008; Available from: http://www.custompartnet.com/wu/fused-deposition-modeling.

[14] Cardona, J.A., An integrated approach for characterization of properties andmesostructure for FDM Ultem 9085, 2010, University of Missouri--Columbia.

[15] Bidanda, B., V. Narayanan, and R. Billo, Reverse engineering and rapid prototyping.Handbook of Design, Manufacturing and Automation, 2007: p. 977-990.

[16] 16.3D Systems, I.3D Systems Completes The Acquisition Of Z Corp and Vidar. 2012. http://www.zcorp.com/en/Press-Room/3D-Systems-Completes-Acquisition-of-Z-Corporation/news.aspx.

[17] CustomPartNet. 3D Printing. 2008, http://www.custompartnet.com/wu/3d-printing.

[18] Jacobs, P.F., Rapid prototyping & manufacturing:fundamentals of stereolithography1992: Sme.

[19] Khaing, M.W., J.Y.H. Fuh, and L. Lu, Direct metal laser sintering for rapid tooling: processing and characterisation of EOS parts.Journal of Materials Processing Tech, 2001. 113(1): p. 269-272.

[20] Pessard, E., et al., Complex cast parts with rapid tooling: rapid manufacturing point of view.The International Journal of Advanced Manufacturing Technology, 2008. 39(9): p. 898-904.

[21] Durham, M., T. Grimm, and J. Rollins, SLS and SLA: different technologies for different applications. Promotional Literature, Accelerated Technologies Inc., Austin, TX, 1996.

[22] Antonio, A., Assessment of surface quality on textured FDM prototypes.Rapid Prototyping Journal, 2006. 12(1): p. 35-41.

[23] Weiss, E., et al., Accuracy of parts manufactured by rapid prototyping technology.Annals of DAAAM & Proceedings, 2010(Journal Article): p. 461.

[24] Kulkarni, P. and D. Dutta, Deposition strategies and resulting part stiffnesses in fused deposition modeling.Journal of manufacturing science and engineering, 1999. 121(1): p. 93-103.

[25] Sung-Hoon, A., et al., Anisotropic material properties of fused deposition modelingABS.Rapid Prototyping Journal, 2002. 8(4): p. 248-257.

[26] Pilipović, A., P. Raos, and M. Šercer, Experimental analysis of properties of materials for rapid prototyping.The International Journal of Advanced Manufacturing Technology, 2009. 40(1): p. 105-115.

[27] 3D Systems, I. 3D Systems ProJet™ 6000 Professional 3D Printer. Available from: http://printin3d.com/projet-6000.

[28] EOS. EOS Formiga P100. Available from:99 http://www.eos.info/en/products/systems-equipment/plastic-laser-sintering-systems/formiga-p-100.html.

[29] Dimension. Dimension Elite 3D Printer, http://www.dimensionprinting.com/3d-printers/3d-printing-elite.aspx.

[30] Corporation, Z. Z Corporation Spectrum Z510. http://www.zcorp.com/en/Products/3D-Printers/Spectrum-Z510/spage.aspx.

[31] PROTO3000. Objet Eden350V 3D Printers. http://www.objet.com/3DPrinter/Objet_Eden350_Eden350V/.