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Study On the Effect of Different Build Orientations to The Rapid Prototyping Systems

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Abstract: There are several types of rapid prototyping systems in the market nowadays. So, a study which focus on the comparison between different Rapid Prototyping systems and performance in different build orientations has shown in this study. This research focus on providing general information for dimensional accuracy and tensile properties for different build orientations and relative water absorption properties between different Rapid Prototyping systems. Test specimens were fabricated in four popular commercial Rapid Prototyping systems such as Selective Laser Sintering (SLS), PolyJet, Fused Deposition Modeling (FDM), and 3D Printing (3DP). The results came out from this research can be used as a preliminary guide for users to determine optimal strategies for rapid prototyping system selection.

Keywords: Rapid Prototyping, Dimensional Accuracy, Tensile Properties, Build Orientations, Relative Rate Of Water Absorption

1. Introduction

In many fields, there is great uncertainty as to whether a new design will actually do what is desired. New design often have unexpected problems. A prototype is often used as part of the product design process to allow engineers and designers the ability to explore design alternatives, test theory and confirm performance prior to starting production of new products. Prototype also can used as market survey to test for the customers' demand.

Manufacturing cost is something that manufactures most concern about. In order to reduce producing product cost, people preferred to put the cost from the start of manufacturing process so that there is no product defect in future. Parameter control would be a significant role to reduce plastic product defect in every production. In rapid manufacturing process, methodically designed to provide a mass- customized product to achieve a desired balance among cost, throughput, and quality is a mass challenge for engineers and designers [1].

The traditional rapid prototyping methodology is hard to be used because different sets of parameters give different implementations. [2] Proposed that a prototyping framework for such systems which allows designers to rapidly create a prototype and efficiently test against parameters. For a given

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system specification, the collected parameters are determined in software to facilitate the modification during system tuning. The other parts represent the core computations that are required to compute a correct solution. This portion can be implemented as an early partial prototype and then connected to the software part that computes parameter values. By doing so, designers can find satisfactory parameters under realistic computing situations. That approach provides the benefits of rapid specification, flexible tuning, hardware/software capability, and shorter development process.

Rapid prototyping (RP) refers to the technologies that are capable of producing prototypes from Computer aided design (CAD) data [3]. It is increasingly being used by industry as it offers significant advantages in terms of time and cost reduction and improved quality of the final product. However the advent of a variety of rapid prototyping technologies such as Stereolithography, laminated object manufacture, fused deposition modelling and selective laser sintering have put the user in a dilemma as to which technology offers the best solution to their needs. [4] This may be further complicated by the many secondary processes such as vacuum casting. Current research in rapid prototyping concentrates mostly on the improvement of existing process and materials development and the development of new processes and materials [5].

Since the introduction of rapid prototyping technology as a tool for time compression and concurrent engineering in the design and manufacturing process, many enhancements and refinements have been made based on the experience of users and manufacturers of rapid prototyping equipment. These improvements contribute significantly to better production of quality output from rapid prototyping systems. This project will review the different type of RP systems and their performance in different build orientations. This will help users who want to undergoing rapid prototyping can select a suitable rapid prototyping system to produce the products.

2. Materials and Methods

The materials and methods section, otherwise known as methodology. Methodology can be defined as systematic and standardized procedure or process which can be apply in a field of study. In this chapter, the method/process to conduct this case study will be discusses. A research must have a clear methodology which can provide a clear mind-set to help in achieve the objective of research.

2.1 Materials

Materials used in this study were polyamide 12, UV curable acrylic plastic, ABS plastic and gypsum [6]. The test specimens were fabricated by these four RP systems in three build orientations as shown in Figure 1 below. The test specimens were draw out by using SolidWorks 2019.

Table 1: Materials used in Rapid Prototyping systems.

System	Material
SLS	Polyamide 12
PolyJet	UV curable acrylic plastic
FDM	ABS plastic
3DP	Gypsum

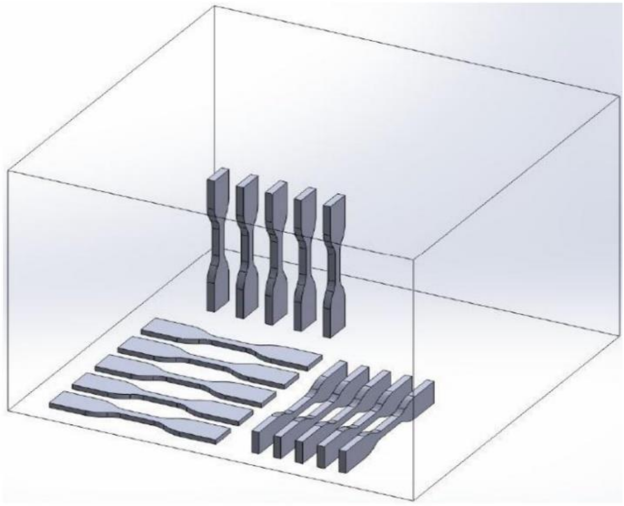

Figure 1: Specimens in three build orientations in each RP system.

The tensile properties of specimens were determined according to the ASTM D638 Type IV. The dimensions of the specimen was shown as Table 2 below and the shape of test specimen will showed as Figure 2 below.

Table 2: Dimensions of specimen (ASTM D638 Type IV).

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

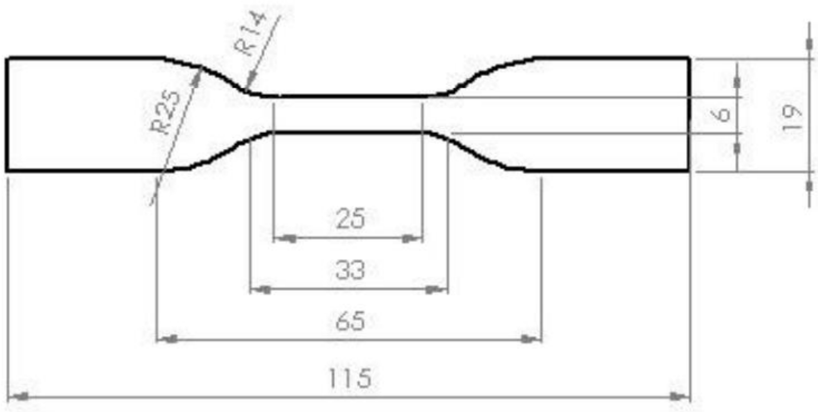

Figure 2: Shape of test specimen (mm).

2.2 Methods

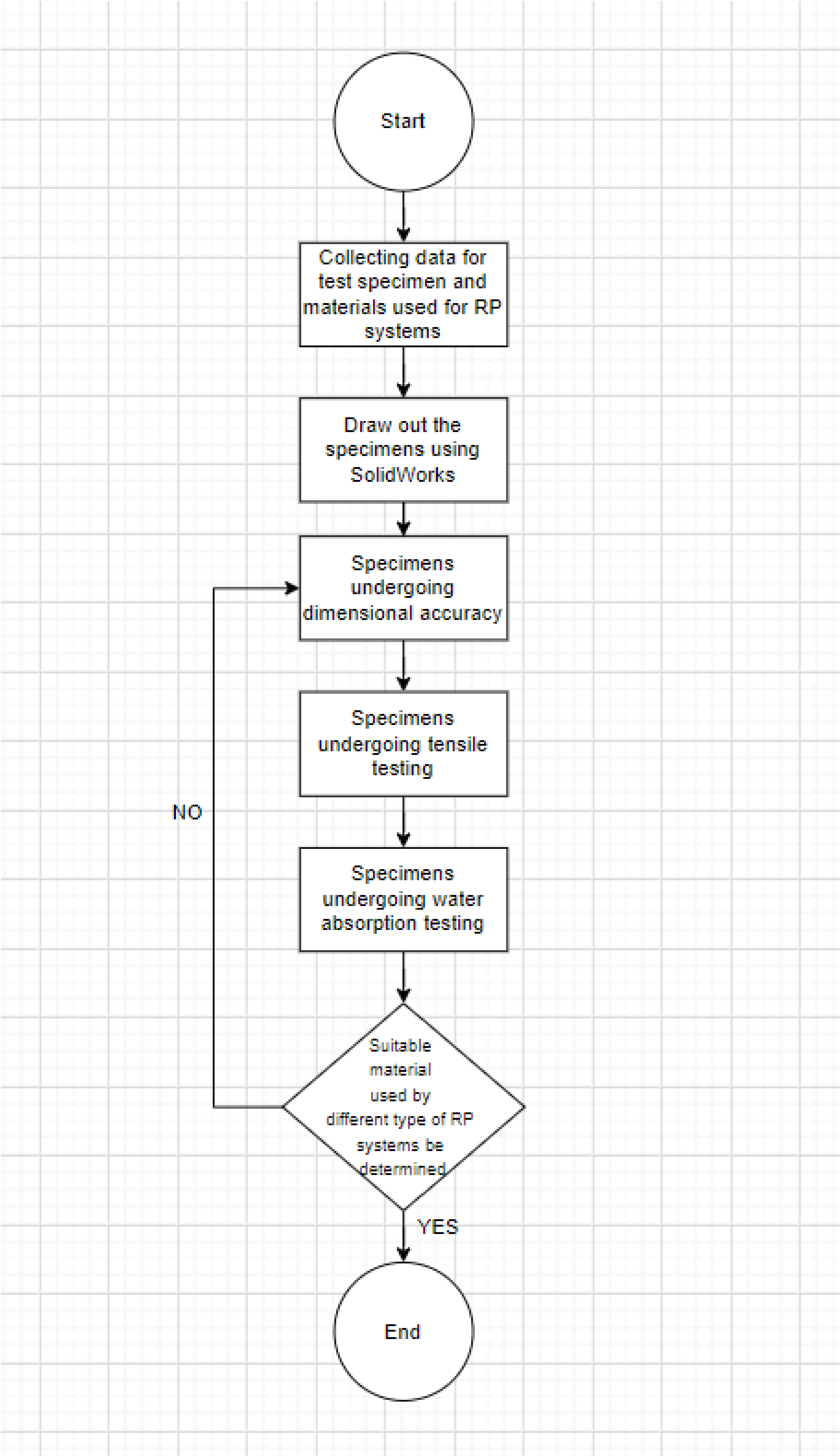

Figure 3: Flow Chart of Methodology.

2.3 Equations

The formula for the calculations will be show as below:

Dimension Change Rate (percent),

$$= \left[\frac{Measured\ value\ (mm)}{Desired\ value\ (mm)} - 1\right] \times 100 \quad (1)$$

Dimensional Accuracy (percent),

$$= \left|\left[\frac{Measured\ value\ (mm)}{Desired\ value\ (mm)} - 1\right] \times 100\right| \quad (2)$$

Water absorption (percent)

$$= \left[\frac{Weight\ after\ conditioning\ for\ 24\ hours(g) - initial\ weight\ (g)}{initial\ weight\ (g)}\right] \times 100 \quad (3)$$

Eq.1 is the equation to calculate the dimension change rate in percent. While Eq.2 was used to calculate the dimensional accuracy of the test specimens used in percent. Lastly, the Eq.3 was used to calculate the water absorption in percent by the test specimens after the experiment.

3. Results and Discussion

3.1 Dimensional accuracy

All of the dimensional accuracy of specimens were measured before undergoing the tensile property test. The dimensional accuracy for each measurement point and built orientation for the different RP systems will be discussed.

Based on the table and figure below, the PolyJet had the best dimensional accuracy. The Horizontal is more accurate (0.323%) compare to the Side (1.222%) and Vertical orientation (1.814%) for PolyJet, FDM and 3DP. While for SLS, the Vertical build orientation (0.509%) has more dimensional accuracy than Side (1.483%) and Horizontal orientation (2.214%).

Table 3: Dimensional Accuracy Summary

RP System	Build Orientation	Dimensional Accuracy (%)
SLS	Side	1.483
	Horizontal	2.214
	Vertical	0.509
PolyJet	Side	1.222
	Horizontal	0.323
	Vertical	1.814
FDM	Side	2.213
	Horizontal	1.103
	Vertical	2.185
3DP Before Harden	Side	4.088
	Horizontal	2.687
	Vertical	2.935
3DP After Harden	Side	3.986
	Horizontal	2.530
	Vertical	2.836

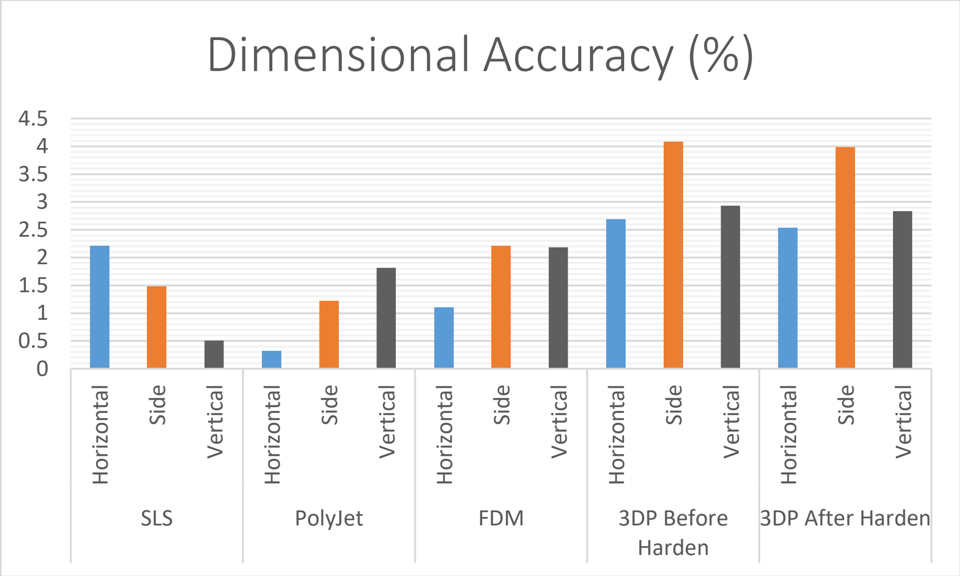

Figure 4: Dimensional Accuracy Summary

3.2 Tensile Properties

Different in build orientations within the different RP systems does affect the tensile strength of the specimens. It was found that PolyJet gave the greatest value of tensile strength, followed by SLS, FDM and 3DP respectively if considering effect of using different types of rapid prototyping systems. While if considering build orientation, the samples created in Side orientation in PolyJet, FDM, and 3DP showed the greatest tensile strength compared with Horizontal and Vertical samples.

However, Elongation and Elongation at Break are different samples created in different orientations in the same RP system. 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 only depend on the layers.

It can be found that the experiment results of Tensile Strength are generally close to the data provided by the manufacturer. Considering the Elongation and Elongation at Break, the experiment results of the SLS, PolyJet, and FDM are not as high as the data provided by the manufacturers. Therefore, further investigation is necessary.

Table 4: Tensile Properties Summary

RP System		Tensile Properties		
		Tensile Strength (psi)	Elongation (%)	Elongation at Break (%)
	Side	7122.800	7.330	15.736
	Horizontal	7367.400	7.455	16.533
SLS	Vertical	6801.800	7.741	12.467
	Company	6962	NA	24
	Side	9728.200	4.088	5.754
	Horizontal	8868.200	3.913	5.064
PolyJet	Vertical	5137.400	1.608	1.624
	Company	7250-9450	NA	10-25
	Side	5572.200	2.182	3.710

	Horizontal	4283.800	2.219	3.383
	Vertical	3563.200	1.408	1.423
FDM	Company	5300	3	NA
	Side	2442.250	0.497	0.513
	Horizontal	2182.375	0.498	0.514
3DP	Vertical	2249.875	0.383	0.399
	Company	2059.535	NA	0.23

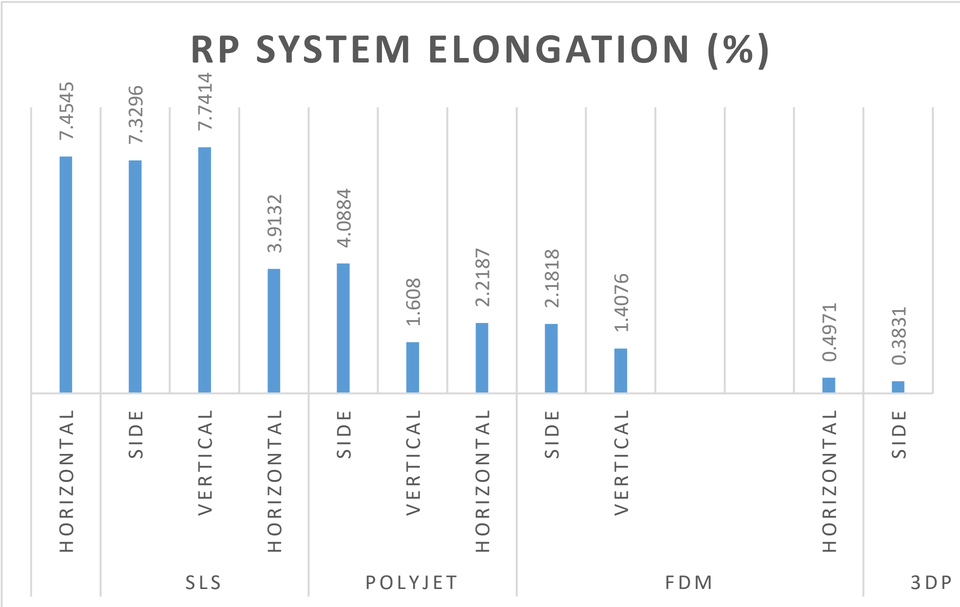

Figure 5: Rapid Prototyping System Elongation

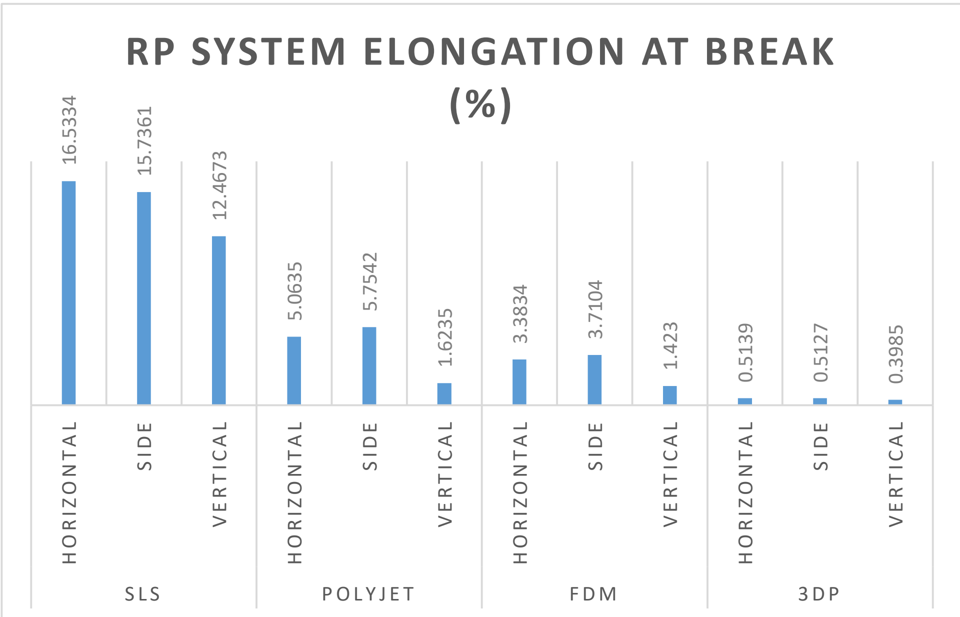

Figure 6: Rapid Prototyping System Elongation at Break

Table 5: Maximum and Minimum stress and strain for four system through simulation in SolidWorks 2019

	Maximum		Minimum	
	Stress (N/m^2)	Strain(N/m^2)	Stress(N/m^2)	Strain(N/m^2)
SLS	9.459e+06	7.596e+03	1.126e+07	1.176e-03
PolyJet	9.456e+06	6.683e-03	1.118e+07	1.003e-03
FDM	9.071e+06	8.564e-03	1.084e+07	1.116e-03
3DP	8.966e+06	5.332e-03	1.075e+07	6.668e-04

3.3 Water absorption

There are several of plastic materials absorb varying amounts of water and this will affect plastics in different ways. The increase in dimensional variations, weight and the change in electrical and mechanical properties may need to be considered before using plastic materials for different purposes.

The highest relative rate of water absorption appeared in the test specimens by FDM technology with 11.273%, while the lowest relative rate of water absorption can be found in the samples created by PolyJet technology with 1.170%. The distributed structure and the type of materials used in specified rapid prototyping systems will affects the relative rate of water absorption. Powder-based materials will absorb water better than liquid-based material which is used in PolyJet technology. In 3DP technology, an ink-jet printing head deposits a liquid adhesive that binds the powdered material. The post-processing to infiltrate printed parts in hardener is needed to improve strength in 3DP technology.

In SLS technology, the carbon dioxide (CO_2) laser heats powdered materials layer by layer so that the surface tensions of the grains are overcome and they fuse together to form a new deposited layer. The materials used in 3DP and SLS are both powder based which are gypsum powder for 3DP and nylon powder for SLS.

However, the different ways the layers are bonded and the different materials used in 3DP and SLS affect the weight change when immersed in water. The relative rate of water absorption of samples at the end of test (24 hours) is in the order of: FDM > 3DP > SLS > PolyJet.

Table 5: The relative rate of water absorption in four RP systems

RP System	Sample	Wight (g)		The relative rate of water absorption (%)
		Before	After	
SLS	1	6.677	6.860	1.329
	2	6.830	6.940	1.611
	AVG	6.800	6.900	1.470
PolyJet	1	7.690	7.780	1.170
	2	7.700	7.790	1.169
	AVG	7.700	7.790	1.170
FDM	1	5.850	6.560	12.137
	2	5.860	6.470	10.440
	AVG	5.860	6.520	11.273
3DP	1	10.650	11.460	7.606
	2	10.650	11.200	5.164
	AVG	10.650	11.330	6.385

4. Conclusion

Throughout the analysis of this comparative study, rapid prototyping users who was interested in optimizing production will have an idea of the effect on dimensional accuracy and tensile properties of different build orientations and RP technologies as well as the effect of different RP technologies on water absorption.

The results obtained in this paper include dimensional accuracy and tensile properties for different build orientations and the relative rate of water absorption between different rapid prototyping systems: SLS, PolyJet, FDM and 3DP. Most of the experiment results were tested to be statistically significant in the SLS, PolyJet, and FDM, with the exception of 3DP in dimensional accuracy (p-value = 0.091) and tensile properties (p-value = 0.052).

In the 3DP technology, the post-processing which manual dipping parts in the binder may cause the variation in the experiment. Different build orientations will had a significant effect on dimensional accuracy and tensile properties in the SLS, PolyJet, and FDM. Considering dimensional accuracy in different build orientations, Horizontal was more accurate compared with Side and Vertical in the PolyJet, FDM and 3DP with the exception of the SLS system. In the SLS, Vertical build orientation was more accurate compared with Horizontal and Side orientation

Considering the relative rate of water absorption, all specimens created in the PolyJet had the greatest performance which is the lowest water absorption. Through analysis of the comparative data, the information can be used as a preliminary guide to help users to determine optimal strategies for selection of rapid prototyping systems and build orientation of the specimens. However, the cost of particular rapid prototyping machines was not possible to provide a definitive statement as the list prices and machine specifications change regularly.

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