FDM 400mc Accuracy Assessment

By Jesse Hanssen, Stratasys, Inc.

Figure 1: To document accuracy, precision and repeatability, the FDM 400mc was subjected to an in-depth assessment.

Material: ABS-M30

Tip: T16 [0.016 in. (0.41 mm) dia.]

Slice: 0.010 in. (0.25 mm)

Style: Solid

Supports: WaterWorks™ (soluble)

Build parameters:

Default—0.020 in. (0.51 mm) road width;
90° delta angle

Figure 2: Test part construction parameters

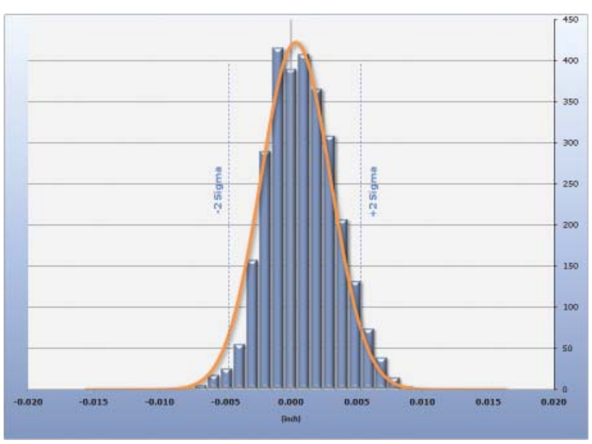

Figure 3: Histogram with normal distribution curve for dimensional deviation of all measurements shows a standard deviation of 0.0027 inch (0.07 mm) centered on a mean of 0.00034 inch (0.009 mm).

Applications beyond concept modeling and general prototyping have stringent demands for qualifying a process' capabilities. For advanced prototyping, analysis and the growing number of direct digital manufacturing (DDM) projects, accuracy assessments must be comprehensive studies based on sound quality control practices.

To quantify the capabilities of the FDM® 400mc™, Stratasys performed an in-depth analysis of accuracy, precision and repeatability. The study of the system's process capabilities confirmed the FDM 400mc's published tolerance specifications and showed a high degree of repeatability across machines, builds and platform locations.

Real-World Testing

The assessment of dimensional accuracy was based on 108 sample parts and 2,916 measurements. The test parts were constructed on three FDM 400mc machines. There were three builds on each machine, and each build had a full platform of 12 parts.

The test part (Figure 1) measured 5.0 X 3.0 X 0.55 inches (127 X 76 X 14 mm). It was constructed in ABS-M30 with standard parameters (Figure 2). Other than support removal, there was no secondary finishing.

There were no adjustments made prior to, or during, the study that would improve the overall accuracy or the quality of a feature. Additionally, all test parts and all measurements were included in the data analysis—rebuilds and measurement exclusions were not permitted. With a CMM, QC Inspection Services, Inc. (Burnsville, Minn.) measured each test part in 27 locations.

Real Results

The results of the accuracy study confirmed that the FDM 400mc produces parts to a tolerance that is the greater of ±0.005 inch (0.13 mm) or ±0.0015 inch/inch (0.04 mm/mm). The specification is based on a 95 percent certainty level (two sigma).

Of 2,916 measurements, 2,804 passed (96.2 percent). Of the 112 measurements that exceeded the tolerance specification, only 45 (1.54 percent) were more than 0.001 inch (0.03 mm) beyond the allowable tolerance band.

The histogram (Figure 3) reports the deviation from nominal dimensions from all parts on all FDM 400mc machines. It shows both the number of occurrences by deviation range and the normal distribution curve. This normal distribution has a standard deviation of 0.0027 inch (0.07 mm) centered on a mean of 0.00034 inch (0.009 mm).

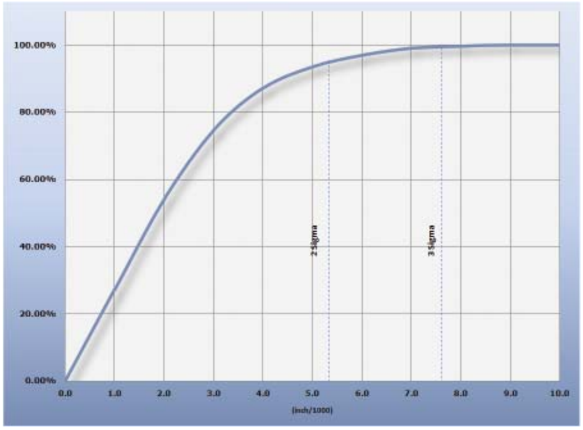

Figure 4: Probability curve, which plots the absolute dimensional deviation, shows that 95 percent of all measurements were within ±0.005 inch (0.13 mm).

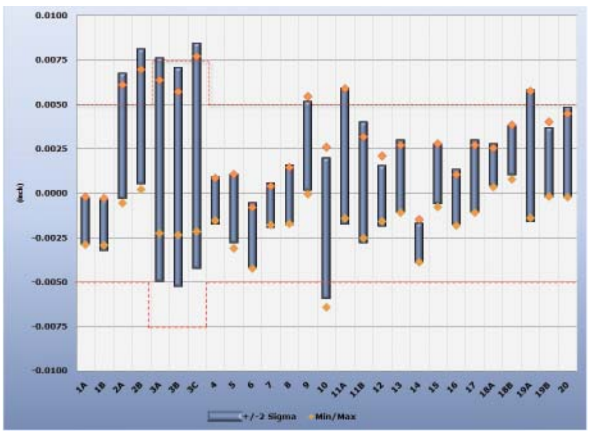

Figure 5: Dimensional deviation plot for all parts from one FDM 400mc. Plot shows acceptable tolerance band (red lines), two sigma value (blue bars) and min/max deviations (orange diamonds).

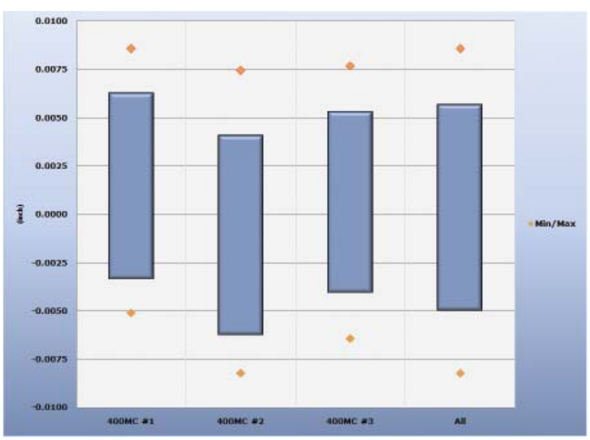

Figure 6: Plot of two sigma values of dimensional deviations by machines shows consistent results with small variation in mean values. This information could be used for fine-tuning to achieve consistent results across all machines.

The normal distribution shows a two sigma capability, which gives a 95.4 percent certainty, of -0.0050 to +0.0056 inch (-0.13 to +0.14 mm). Included in the two sigma calculation are 108 measurements (3.7 percent) with an allowable tolerance of 0.0075 inch (0.191 mm).

Figure 4 is an alternative representation of the tolerance expectations for the FDM 400mc. This probability curve reports the percentage of measurements by their absolute deviations. It shows that nearly 80 percent of the measurements were within ±0.003 inch (0.08 mm), 95 percent were within ±0.005 inch (0.13 mm) and 100 percent were within ±0.008 inch (0.20 mm).

Figure 5 plots the dimensional deviations, by location on the test part, for a single FDM 400mc. The red, dashed lines indicate the acceptable tolerance band per the published specification. As shown, all locations have a two sigma value that is well within the tolerance range. This indicates that a slight adjustment of the CAD data, build parameters or machine calibration would be likely to increase the number of measurements that meet the quality standard. As with any manufacturing method, a sampling run would be followed by fine-tuning of the process parameters to increase production yields.

A common objection to direct digital manufacturing (DDM) is that additive fabrication technologies have unacceptable variances from part-to-part, build-to-build and machine-to-machine. To analyze the variance of the FDM 400mc, the machine number, build number, and platform location were documented for each test part. The results indicate that the FDM 400mc is a stable platform with repeatable dimensional accuracy.

Figure 6 reveals consistent performance between the three FDM 400mc machines. The slight variation between them was due mostly to the mean deviation. The mean values for FDM 400mc #1, #2 and #3 were 0.0015 inch (0.04 mm), -0.0011 inch (0.03 mm) and 0.0006 inch (0.02 mm), respectively. If manufacturing parts, the machines would be adjusted to bring average deviations closer to zero. This could further improve the repeatability of the output quality from machine-to-machine. Figure 7 shows that once dialed in, the output would be very consistent from build-to-build.

The dimensional deviations for three runs on one FDM 400mc are presented in Figure 7. Although the test parts were built over multiple days and each machine required one material replenishment, the two

The FDM Process

FDM® (fused deposition modeling) is a direct digital manufacturing process patented by Stratasys, Inc. The FDM process creates functional prototypes, tooling and manufactured goods from engineering thermoplastics, such as ABS, sulfones and polycarbonate, as well as medical versions of these plastics.

FDM machines dispense two materials—one for the model and one for a disposable support structure. The material is supplied from a roll of plastic filament on a spool or in a cartridge. To construct the model, the filament is fed into an extrusion head and heated to a semi-liquid state. The head then extrudes the material and deposits it in layers as fine as 0.005 inch (0.127 mm) thick.

Unlike some additive fabrication processes, FDM requires no special facilities or ventilation and involves no harmful chemicals and byproducts.

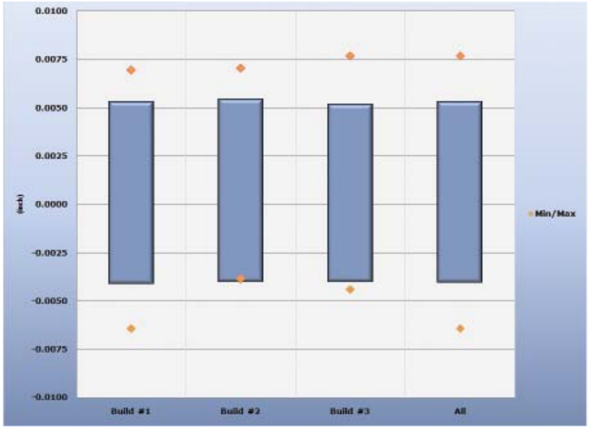

Figure 7: Comparison of dimensional deviation across builds on a single FDM 400mc shows consistent two sigma and mean values.

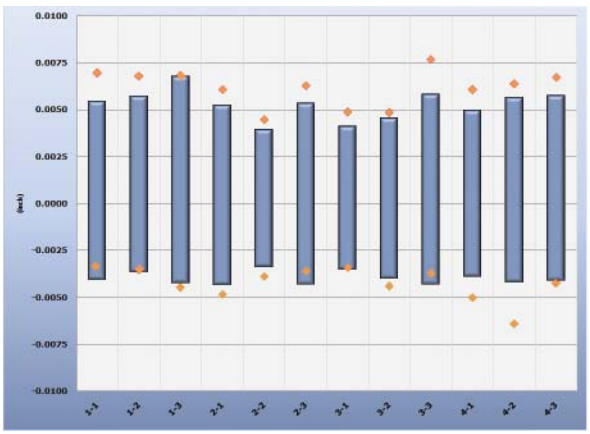

Figure 8: Two sigma values of dimensional deviations across 12 locations of sample parts in one build show that part placement has little effect on dimensional accuracy.

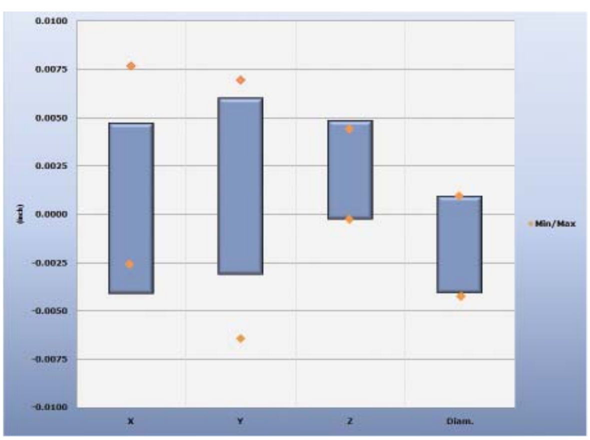

Figure 9: Plot of dimensional deviations (two sigma) by measurement axis. Results for cylindrical measurements in the XY plane are also listed.

sigma capability was extremely consistent. The mean values had a variance of just 0.00014 inch (0.003 mm), and the standard deviations differed by only 0.00007 inch (0.002 mm).

Figures 8 and 9 present more evidence of consistency in dimensional accuracy. The results show little difference between parts built in any of the 12 locations on the build platform, and tolerances along the X-axis are consistent with those along the Y-axis.

Real Solution

The accuracy assessment confirmed that the FDM 400mc manufactures parts to published tolerance specifications. Across three machines, 108 parts and 2,916 dimensions, it delivered predictable and repeatable results.

From its inception, a design goal for the FDM 400mc was to improve on the accuracy of FDM systems to address the requirements of manufacturing. The assessment, which was conducted on all FDM systems, showed considerable improvement in dimensional accuracy and repeatability. In both areas, the FDM 400mc proved to be superior to the systems that preceded it. Having achieved the design goal, it is believed that the FDM 400mc would also demonstrate this superiority over other additive fabrication technologies if tested under the same conditions.

Demonstrating consistent and repeatable accuracy, the FDM 400mc is suited for manufacturing applications. Predictability facilitates fine-tuning of the process parameters to dial-in the required dimensional accuracy. Once dialed-in, the FDM 400mc will consistently manufacture parts from day-to-day and build-to-build.

For the complete accuracy assessment report, contact a Stratasys, Inc. representative at (952) 937-3000 or visit www.stratasys.com.

For more information about Stratasys systems and materials, contact your representative at +1 888.480.3548 or visit www.stratasys.com

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