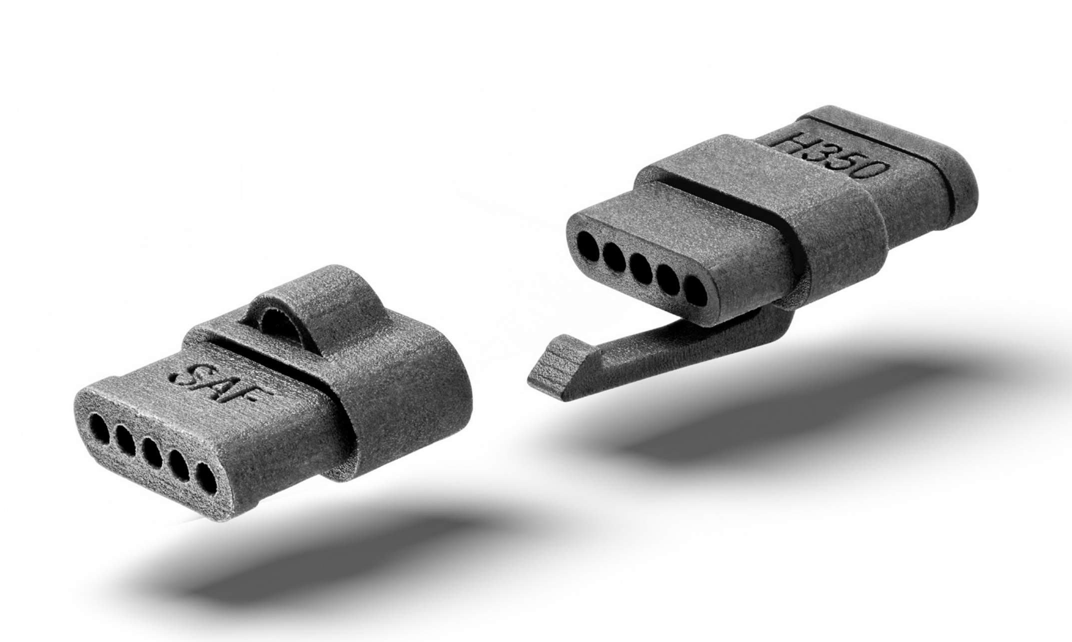
Consistent Additive Manufactured Production Grade Parts



White Paper

stratasys

Consistent Additive Manufactured Production-Grade Parts

Abstract

This paper provides the methods and results for assessing geometric accuracy of the H350™, using a Stratasys designed giveaway part. The part is representative of a potential end use of the H350 and is built many times across the bed. The H350 allows customers to qualify their production to produce consistent additively manufactured production-grade parts using SAF™ technology. With SAF™, customers can control part qualities build-to-build in a way that optimizes part performance, consistency and ultimately production yield, leading to less waste and a lower cost per part.

Test information

The Part

Taking the form of an automotive electrical connector, the part used in this whitepaper was designed by Stratasys as a giveaway part to illustrate the capability of the H350 using a part representative of potential end-use part. This is shown in Figure 1.

A connector was selected as a suitable geometry to demonstrate SAF's capabilities. This can be shown geometrically, with several dimensions which can be easily measured to validate the accuracy and repeatability of the process, and in nesting, with the part packing densely into the H350 build volume. The design of the connector differs slightly from what might be expected of an end-use connector, this reflects its different function. The connector is designed to give recipients a tactile demonstration of SAF parts. It is intended to be handled, connected and disconnected repeatedly by recipients without becoming loose. To achieve this, the pair is designed with a tight clearance of only 0.1 mm. This provides a secure but free running clearance fit. The connector also features a robust, chunky clip which provides a secure, positive engagement but is more easily manipulated than real-world counterparts.

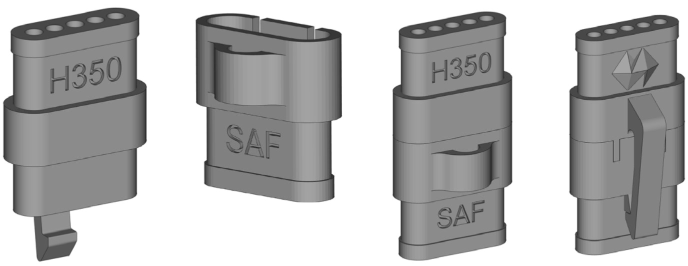


Figure 1: The giveaway automotive connector separately and assembled

The Build

Figure 2 shows the parts nested in the build volume and provides a realistic but challenging build, typical to manufacturing customers in a production environment.

The build consists of 128 pairs of connectors, with the male and female parts built on top of each other. This ensures the best chance of pairs fitting together as per Stratasys' Tips and Tricks. The total 256 parts have a build density of 23.5% after scaling, nearly double the nominal for SAF technology. In order to demonstrate the H350's abilities, this paper provides the results of geometric accuracy across both the build volume and three consecutive builds on the same machine. This enables users to more comprehensively understand the opportunities SAF technology provides in the consistent additive manufacturing of production-grade parts.

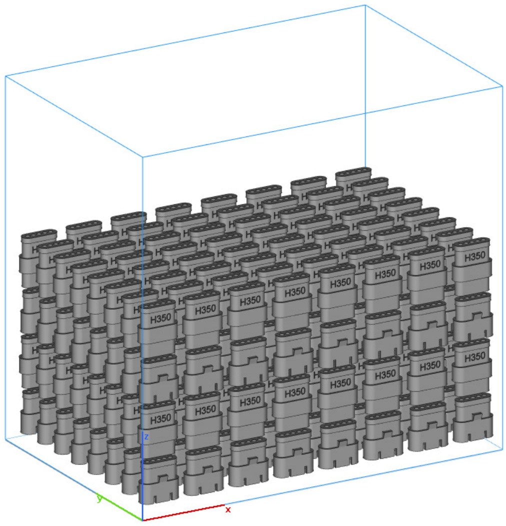


Figure 2: The Automotive connector build

Test information

Machine Parameters

The builds were built at the nominal temperature and scaling factors as identified by the standard machine calibration process. This was designed to give a good balance between mechanical performance and part aesthetics. The powder refresh ratio was 70:30, as is standard with the H350.

Post Processing

The parts received a standard out-of-machine 24-hour cooldown and were then unpacked by hand. A 3mm drill bit was used to create an airway for the holes on both halves of the connector. This was done to aid automated powder removal and did not influence the hole diameter, due to the intentional undersizing of the drill bit. The parts were then depowdered with a DyeMansion PowerShot C using glass media at 3.5 bar for 15 minutes. Each build was run in one cycle.

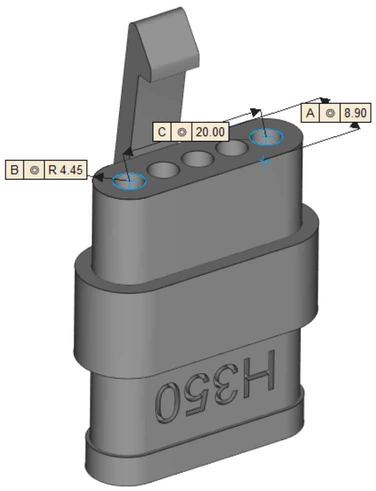
Test information

Measurement

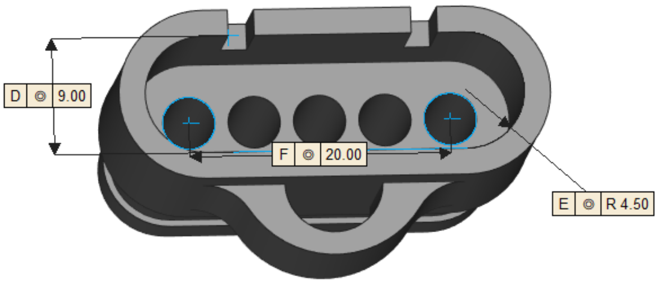
The parts were measured using a Mitutoyo Touch Probe CMM.

Three critical measurements were taken from each connector half to ensure proper operation. Details of these can be seen below. The tolerance on all measurements is ±0.3mm.

Part	Label	Feature	Measurement	Nominal (mm)
Male	A	Thickness	External	8.9
Male	B	Cylinder Edge Radius	External	4.45
Male	C	Hole 1 to 5 Centre	Internal	20



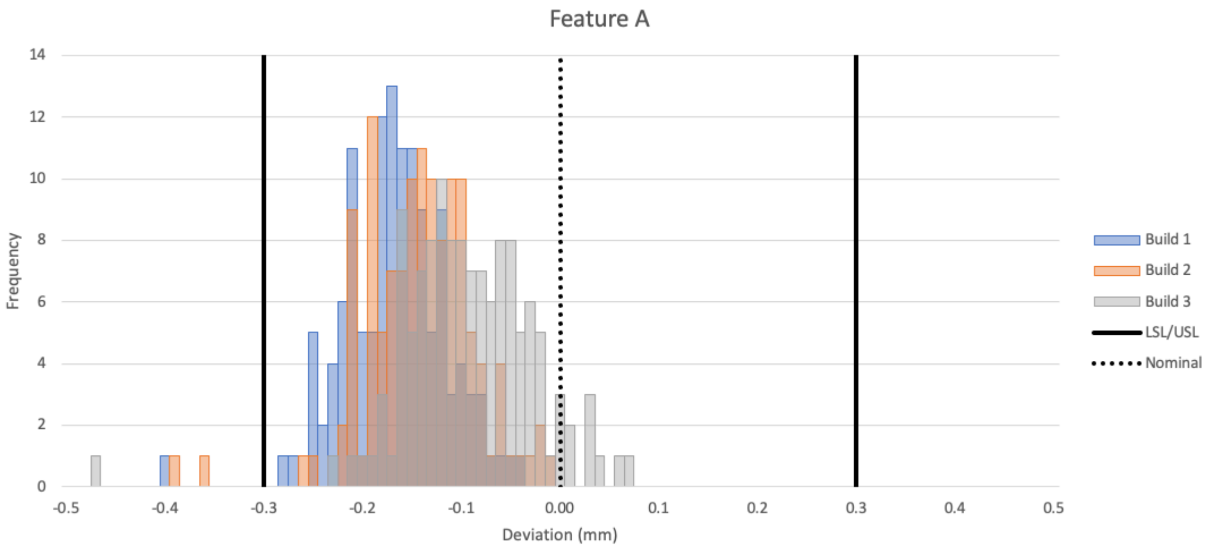
Part	Label	Feature	Measurement	Nominal (mm)
Female	D	Inner Width	Internal	9
Female	E	Inner Radius	Internal	4.5
Female	F	Hole 1 to 5 Centre	Internal	20



Results

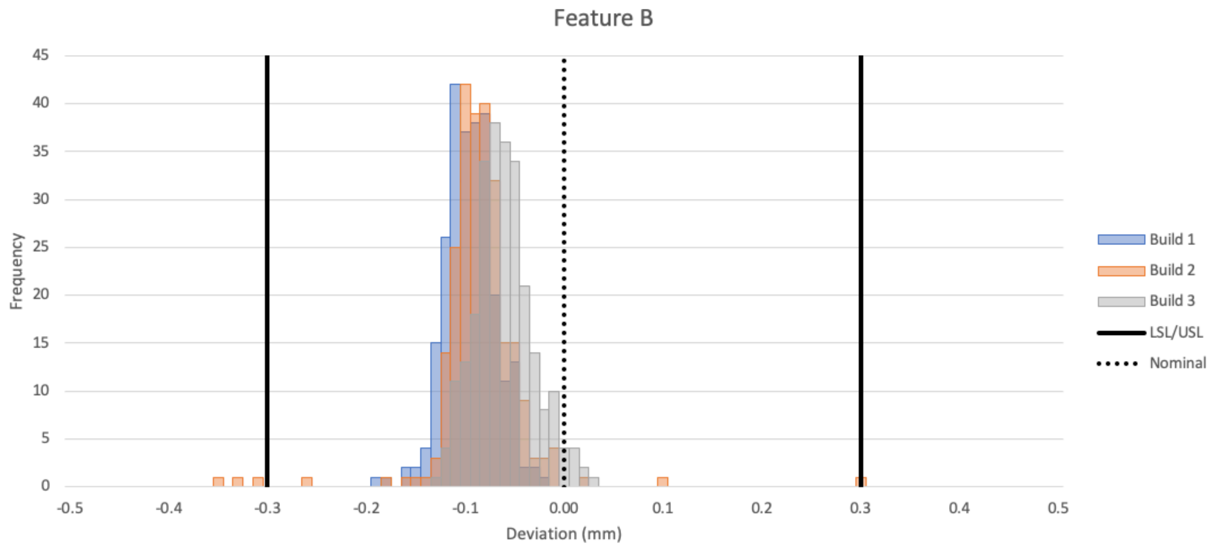
Fit Test

To accurately fit the purpose of the application, the parts must be assembled, disassembled, and reassembled. This is a straightforward pass or fail criteria and was performed by our operators immediately after the automated depowdering process. A 100% pass rate was achieved with the parts paired randomly within each build, indicating high consistency and interchangeability.

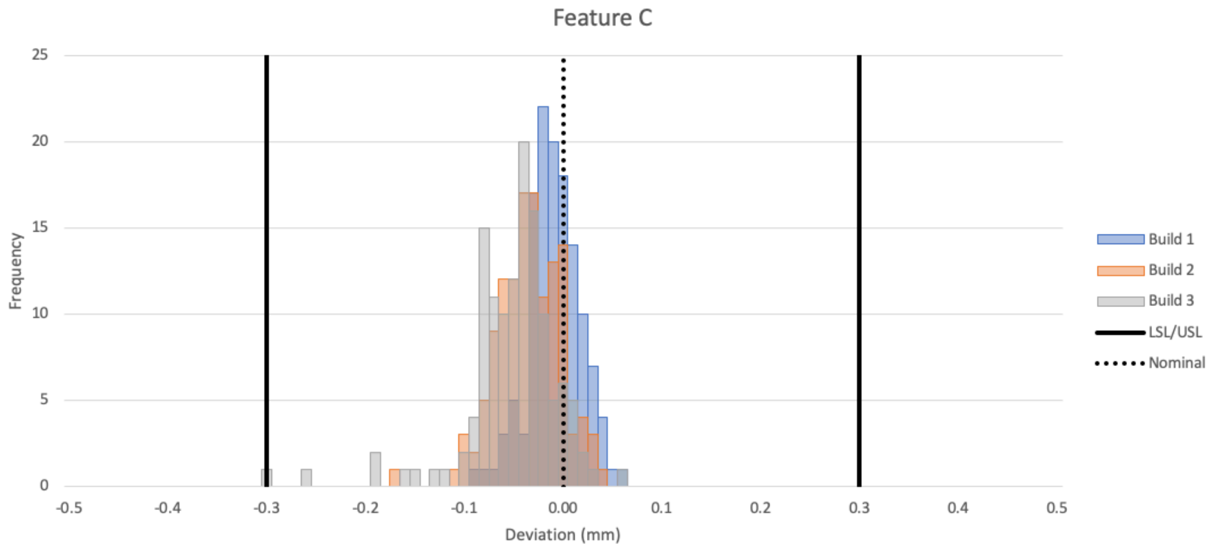


Feature A is mostly in spec but contains some outliers below the lower spec limit (LSL). The individual builds are consistent, with the mean deviation (peak of the histogram) from each build within 75µm. Overall, the feature achieves a 99.0% yield with a CPK of 0.9 and the spread remains consistent with IT15 according to ISO286-1.

Results

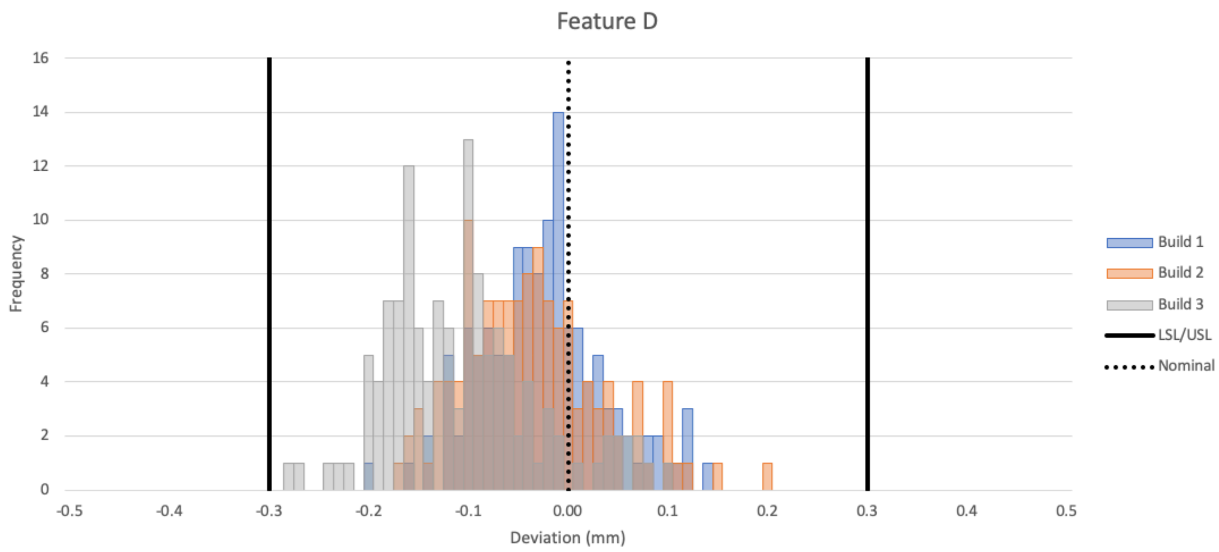


Feature B signifies many of the same behaviors as feature A. This shows tight grouping between builds and a few low outliers that lie outside of the LSL. The histogram peaks all lie within 35µm of each other and the feature overall achieves a yield of 99.5%, a CPK of 2.0 and the spread is consistent with IT14.

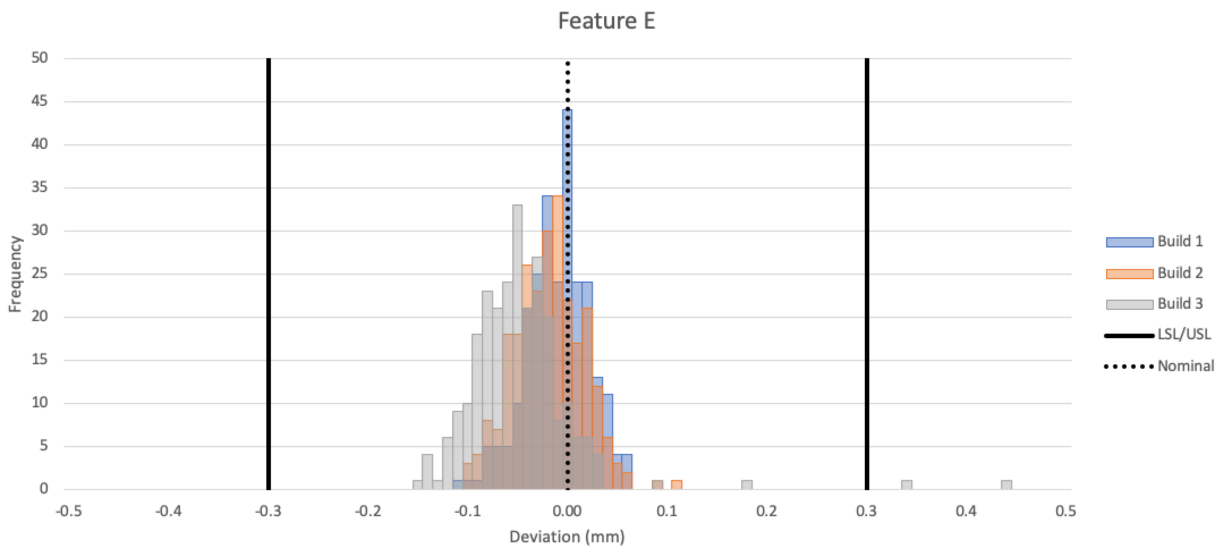


Feature C is very well centred and features minimal outliers. The range between histogram peaks is 42µm and the feature overall achieves a yield of 100%, a CPK of 2.2. The spread is consistent with IT13.

Results

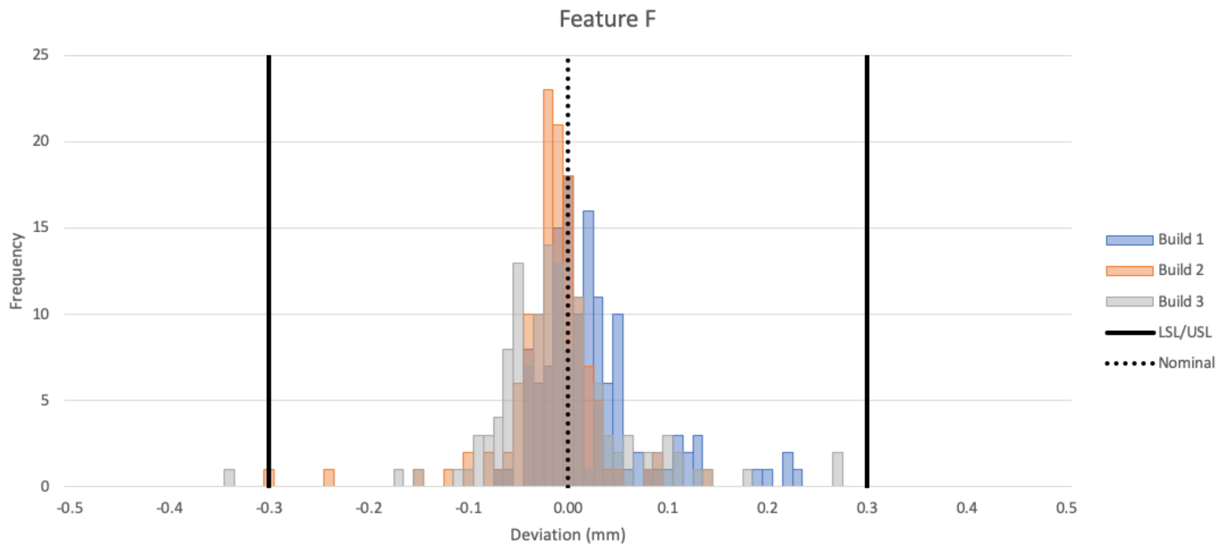


Feature D exhibits a much broader spread than the previous features but is still consistent within builds. It has a range of histogram peaks of 81µm. It also still achieves an overall yield of 100%, a CPK of 1.1 and the spread is consistent with IT15.



Feature E shows upwards outliers , some of which lie outside the upper spec limit (USL). The consistency between builds is still good, with the range of histogram peaks lying within 39µm of each other. It achieves an overall yield of 99.7%, a CPK of 2.1 and the spread is consistent with IT14.

Results

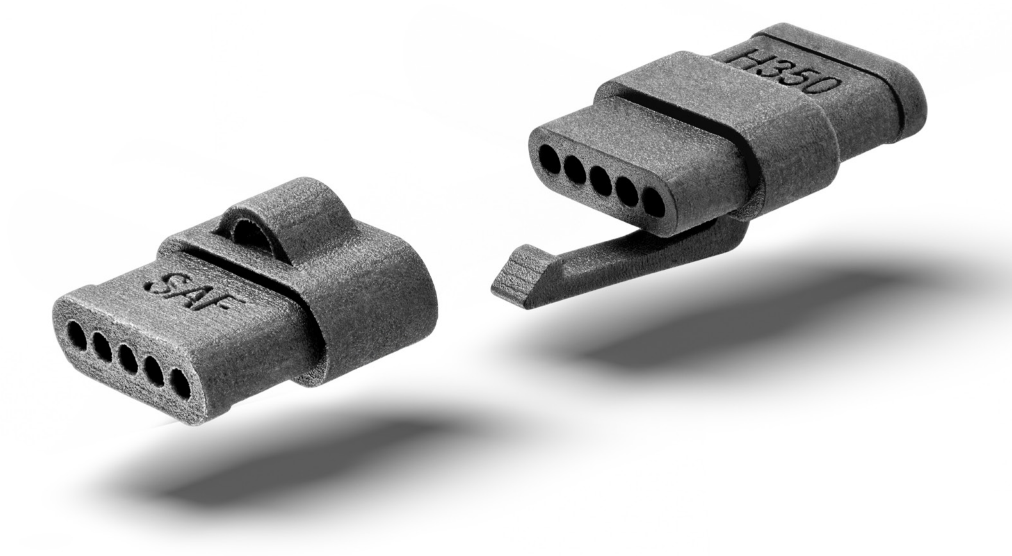


Feature F shows a broad spread, with a few outlier specimens in the extremes of the histogram. The peaks lie within 40µm of each other. It achieves an overall yield of 99.7%, a CPK of 1.6 and the spread is consistent with IT14.

Mechanical

Included in the builds were 30 ASTM D638-14 Type 5 Tensile Specimens. These were preconditioned according to ASTM D618-13 and pulled according to ASTM D638-14 using a Tinius Olsen 5ST Tensile Tester.

The average UTS recorded across the three builds was 41.2MPa (5982 psi).



Summary

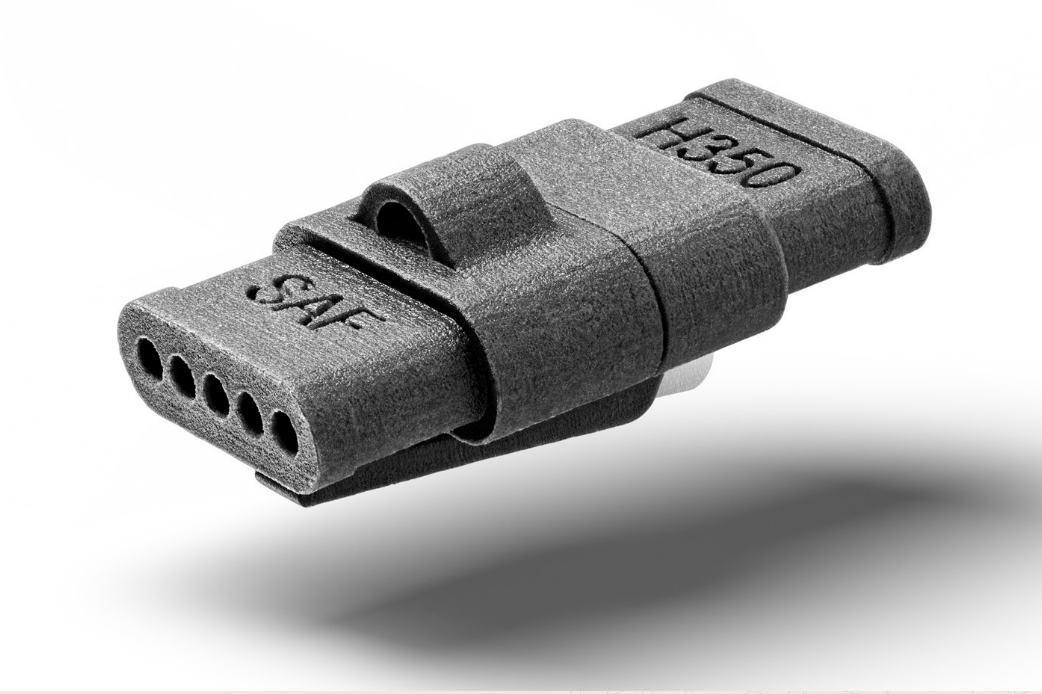
Build 1	Feature A	Feature B	Feature C	Feature D	Feature E	Feature F
Mean Deviation (µm)	-162	-90	-4	-21	-4	29
Standard Deviation (µm)	52	25	26	63	31	55
Yield	99.2%	100.0%	100.0%	100.0%	100.0%	100.0%
CPK	0.9	2.8	3.8	1.5	3.2	1.6
IT Grade	14	13	12	15	14	14
Build 2	**Feature A**	**Feature B**	**Feature C**	**Feature D**	**Feature E**	**Feature F**
Mean Deviation (µm)	-138	-80	-29	-32	-14	-11
Standard Deviation (µm)	57	47	33	69	35	49
Yield	98.4%	98.4%	100.0%	100.0%	100.0%	100.0%
CPK	0.9	1.6	2.7	1.3	2.8	2.0
IT Grade	14	14	12	15	14	13
Build 3	**Feature A**	**Feature B**	**Feature C**	**Feature D**	**Feature E**	**Feature F**
Mean Deviation (µm)	-87	-56	-46	-102	-43	-5
Standard Deviation (µm)	67	29	48	75	56	72
Yield	99.2%	100.0%	100.0%	100.0%	99.2%	99.2%
CPK	1.1	2.8	1.8	0.9	1.5	1.4
IT Grade	15	13	13	15	15	14
All	**Feature A**	**Feature B**	**Feature C**	**Feature D**	**Feature E**	**Feature F**
Mean Deviation (µm)	-129	-75	-26	-52	-20	4
Standard Deviation (µm)	67	38	41	78	45	62
Yield	99.0%	99.5%	100.0%	100.0%	99.7%	99.7%
CPK	0.9	2.0	2.2	1.1	2.1	1.6
IT Grade	15	14	13	15	14	14

Conclusion

The six features identified are critical to the operation of the connector, and the H350 can consistently produce parts that fulfill the criteria required. The lowest yield across any feature is 98.4% (features A and B, build 2) which, given the tight tolerance requirements and high build density, is incredibly high.

Three of the features identified achieve 6-sigma level production consistency across three builds (features B, C and D with CPK values of 2.0, 2.2 and 2.1 respectively). The other features identified achieved CPK values of 0.9, 1.1 and 1.6. This indicates that, if the features are designed well and nested effectively, the H350 is suitable for controlling with SPC in a mass production environment.

The builds produced in this study had an average Z UTS of 41.2 MPa (5982 psi) supporting the fact that the H350 does not compromise mechanical performance or geometric accuracy, allowing the production of production grade parts with confidence.



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