Application News

Precision Universal Testing Machine AGS™-V

3D Printer Using Bayesian Optimization —Optimization of Molding Resin Strength and Molding Time—

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User Benefits

- Excellent results can be achieved with fewer trials with Bayesian optimization.
- When the AGS-V is used, tensile tests can be conveniently performed with excellent precision.

■ Introduction

3D printer technology is widely used in manufacturing and research and development to efficiently produce parts with complex shapes. However, its quality depends on various factors, such as the material used, the forming conditions, and equipment settings. Optimizing these factors is not easy. In particular, to improve performance indicators, such as forming accuracy, surface quality, and strength, it is necessary to adjust a large number of parameters, so traditional methods based on trial and error require large amounts of time and cost.

In recent years, "Bayesian optimization" has been attracting attention as a solution. It is a statistical method that can efficiently search for optimum parameters with a limited number of trials. It is particularly effective for high-dimensional, nonlinear problems.

This article introduces an example in which Bayesian optimization was used on a model for manufacturing tensile test specimens using a resin 3D printer to obtain 3D printing conditions (explanatory variables) that optimized tensile strength and manufacturing times (objective variables).*1

*1 The output conditions obtained in this test are optimal for dumbbell-shaped test specimens, but they may not be optimal for other shapes.

■ Test Conditions

The equipment configuration is shown in Table 1. PETG-CF, which has excellent mechanical strength and high flexibility, was used in the filaments that were the raw materials for the test specimens. Fig. 1 shows the AGS-V precision universal testing machine; Fig. 2 shows the test setup; and Fig. 3 shows the results of a tensile test. The elongation to failure of the PETG-CF used in the filaments was low, and failure occurred in a brittle manner.

Table 1 Equipment Configuration

Testing Machine:	AGS-V
Load Cell Capacity:	5 kN
Test Jigs:	5 kN Non-Shift Wedge-Type Grips
Software:	TRAPEZIUM™ X-V (single)
Test Speed:	10 mm/min
3D Printer:	Bambu Lab X1-Carbon Printer
Filament:	PETG-CF

Fig. 1 AGS™-V Precision Universal Testing Machine

Fig. 2 Test Setup

■ Bayesian Optimization and Procedures

With Bayesian optimization, the test results are input, and the next test conditions are output. This process was performed 6 times, and a total of 30 conditions were tried, so the optimum result obtained was taken to be the optimum solution. The Bayesian optimization conditions are shown in Table 2. In this case, the explanatory variables were set to "layer pitch," "print speed," and "filling density," and the objective variables were set to "maximization of tensile strength" and "minimization of printing time." Table 3 shows the nine conditions and their test results for the first iteration. The Bayesian optimization calculation was performed using a service provided by Mitsui Knowledge Industry Co., Ltd. (MKI-bayesopt).

Table 2 Bayesian Optimization Conditions

Explanatory Variables:	Layer pitch (0.08 to 0.28 mm) Print speed (50 to 2000 mm/sec)*2 Filling density (10 to 100 %)
Objective Variables:	Tensile strength (maximization) Printing time (minimization)
Specimen Shape:	1A type test specimens (JIS K7161-2: 2014)
Trial Conditions:	30 conditions
Number n:	3

*2 The maximum print speed in the specification was 500 mm/sec.

Table 3 First Iteration 9 Conditions

	Explanatory Variables			Objective Variables	
Test No.	Layer pitch (mm)	Print speed (mm/sec)	Filling density (%)	Tensile strength (MPa)	Printing time (min, total for 3 specimens)
1	0.08	300	100	36.63	94
2	0.08	50	80	26.14	119
3	0.08	1000	50	23.53	77
4	0.18	300	100	35.88	63
5	0.18	50	80	32.77	72
6	0.18	1000	50	16.03	53
7	0.28	300	100	32.07	57
8	0.28	50	80	26.45	62
9	0.28	1000	50	21.9	51

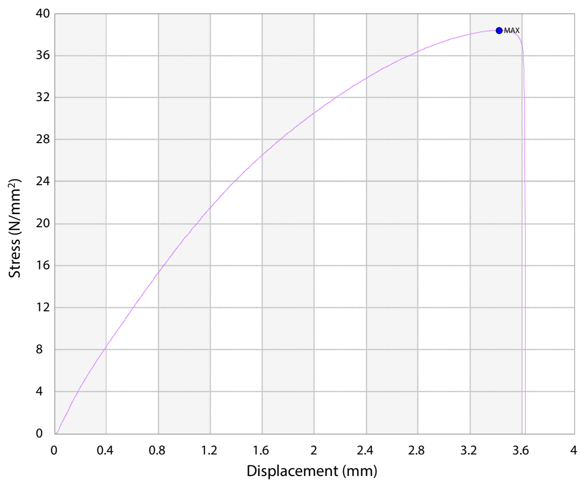

Fig. 3 Example of Tensile Test Result

■ Test Results

The Bayesian optimization trial results are shown in Table 4. For tensile strength, test specimen number 25 (red line) had the optimum conditions, and for printing time, test specimen number 14 (blue line) had the optimum conditions. Fig. 4 is a 3-dimensional chart that shows the correlation between the objective variable tensile strength and the explanatory variables. The orange part indicates high tensile strength, and the blue part indicates low tensile strength. It can be seen that filling density and print speed had a greater effect on strength than layer pitch. Higher filling density and slower print speed tended to produce higher strength. Fig. 5 is a 3-dimensional chart that shows the correlation between the objective variable printing time and the explanatory variables. The orange part indicates longer printing times, and the blue part indicates shorter printing times. The larger the layer pitch, the faster the print speed, and the lower the filling density, the shorter the printing time.

■ Conclusion

The print conditions were optimized for a resin 3D printer using Bayesian optimization, with tensile strength and printing time as the objective variables. It was found that test specimen number 25 had the optimum conditions for strength, and test specimen number 14 had the optimum conditions for printing time. A resin 3D printer that uses inexpensive materials was used in this article, so the objective variables were tensile strength and printing time. However, with metal 3D printers that use expensive materials, minimizing costs could also be an objective variable.

Table 4 Bayesian Optimization Trial Results

		Explanatory Variables			Objective Variables	
Number of optimizations	Test No.	Layer pitch (mm)	Print speed (mm/sec)	Filling density (%)	Tensile strength (MPa)	Printing time (min, total for 3 specimens)
Second	10	0.22	730	100	35.61	59
	11	0.22	50	100	36.28	68
	12	0.28	1120	100	34.22	57
	13	0.15	760	100	37.35	67
	14	0.25	1340	10	19.44	43
Third	15	0.2	1340	100	35.6	62
	16	0.28	750	92	31.27	57
	17	0.09	1340	100	35.17	85
	18	0.24	1340	84	29.29	59
	19	0.13	540	100	38.15	70
Fourth	20	0.23	510	82	29.08	57
	21	0.28	680	10	20.79	44
	22	0.11	690	100	35.54	74
	23	0.17	1340	10	16.66	44
	24	0.28	1340	100	33.21	57
Fifth	25	0.14	210	100	38.19	68
	26	0.28	530	100	33.7	57
	27	0.28	940	24	20.53	46
Sixth	28	0.14	50	100	37.3	84
	29	0.28	50	10	21.13	50
	30	0.14	790	79	29.46	67

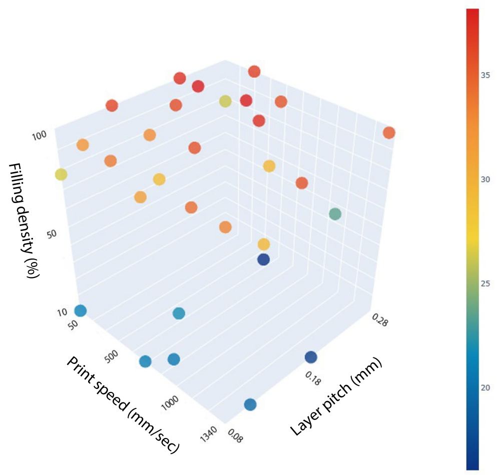

Fig. 4 3-Dimensional Chart with Tensile strength as the Objective Variable

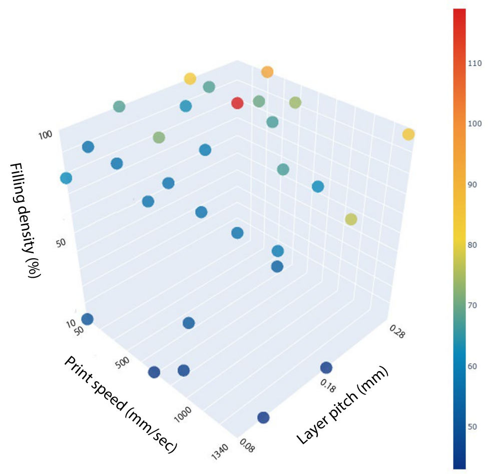

Fig. 5 3-Dimensional Chart with Printing Time as the Objective Variable

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