

# Testing and Evaluation of Concrete Prototypes of Additive Manufacturing using Response Surface Methodology

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**Abstract:** The recent trends of additive manufacturing (AM) is focused on development of large size prototypes which difficult to manufacture by conventional methods. It get hard to obtain standard method guidelines or methodology to develop reproducible model and has target shape oriented in manufacturing. Scaling of additive manufacturing required expertise from practical application which allow knowledge of automated building construction and product process development. Concrete printable unit is used to deposit concrete in case and it studied for building in large scale using additive manufacturing technique. Developing prototype raised challenges in deposition of material due to material deformation at concrete transition from fresh to hardened state. Influence of effective parameter studied including layer thickness, printed orientation and movements. The results of study used to develop tool for predicting deformation of concrete layer in additive process.

**Keywords-** Additive Manufacturing, RSM, Scaling Product Development.

## I. INTRODUCTION

Rapid prototyping is divided into three modes of manufacturing such as additive, subtractive and virtual. Additive manufacturing has huge industrial applications for developing various new industrial machines part prototypes to show variety of new prototype models for presentations. It given clear understanding that, prototyping has increasing demand in technological series applications to minimise wastage of resources and rise in technical production values. Researcher focused on developing small limited part product but it seen lack of knowledge regarding development of large models for industrial applications.

ASTM commented their standards for materials properties and their application. ASTM defined additive manufacturing to joining of materials to manufacture three dimensional object by generating product in layers deposition. It becomes stacked stories of building construction with alternative layer. Additive manufacturing has potential advantage to build industry including labour safety, efficient resources, reduction of cost and time which becomes more economical and sustainable manufacturing technique.

Concrete is most common material in building constructions site lines. It is widely available with better property of strength durability, fire resistance and cost. Therefore, it get popularity in construction sites. Today's additive manufacturing getting challenge in deformability of fresh concrete which becomes difficult to take shape of component part. Therefore its density has given considerable results in significant amount for self-load transition and reduce failure during 3D shape in manufacturing. Mould cavity shape is required to get replica of model which becomes in printable form of testing geometry. All certain kind of curing process can be carried out in mould. This continuous curing getting significant interest in developing large scale 3D model print. The case experiment performed to check deformability and accuracy of layer deposition in concrete material.

Concrete is used in 3D printing process by extrusion techniques which can directly deposited layers through extrusion nozzle point. Some of literatures has detailed about deposition techniques in large scale 3D printing. Contour crafting was invented by Behrokh Khoshnevis with mimic conventional construction process by use of automation techniques. In last decade, D shape structures of moulding, reinforcing has developed. Machine frame along with Y and Z mobile movement was used in printing X direction model construction which help to generate slice structure along X direction. Manufacturing of roof part also possible in additive process with making vertical and support structures. Product model is removed after curing material process. This would be increased in post processing time and cost neglected by advantages of building techniques. It found deformation during deposition becomes in significant interest with yield. Hence to understand large scale 3D printing technique in concrete deposition experimental case study work has carried out to quantify deformation of concrete layer under influence of different process variable.

Large-scale 3D-printing in additive manufacturing of concrete deposition is observed. It is still in its beginning phase in context of conventional product development. The standard guide line has follow to manufacture fundamental adaption of Additive concept of slice binder. Few existing norm and standard guideline are linked with individual adaption of conventional manufacturing method. Guide lines in chronological context of phase product development. The most important representation of VDI guideline 3405 and 2321 and ISO 9000 series of manufacturing standard. Design guideline related to manufacturing operation and work safety operation. This methodology developed and designed technical systems and products in acceptable standards. Wulf 2002 explained phase of product planning and development of precision based procedure model. The phase standard manufacturing

technique sequentially follow in additive process of concrete modelling. This paper explained detailing of yield strength and appearance of concrete deposition on the basis of layered higher, nozzle distance and enlargement of part model.

## II. EXPERIMENTAL WORK

Experimental model work is carried out on simple fixture movable machine based on Cartesian coordinates. The filling and curing deposition of single layer height set to 10-30 mm. Concrete deposition flexibility is given through variation in nozzle diameter of 10-20 mm. Product dimensional factor is studied through its scaling factor for original dimension of component is 250 X 250 X 250 mm size. Figure 1 shows the typical model of concrete deposition layer to manufacturing of layer stack concrete in additive manufacturing method.

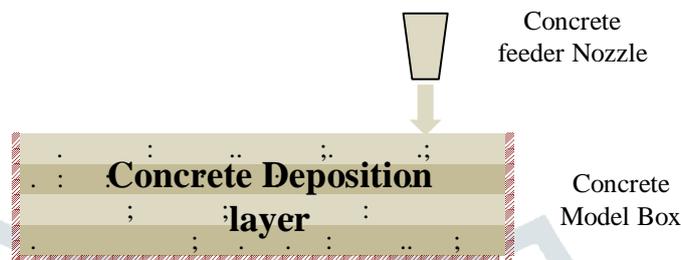


Figure 1 Concrete layer deposition

Following experimental work details are explained on deposition effect in testing of yield strength and appearance feel rate. Response surface method is used to find desirability approach for estimating quality product output. RSM-CCD method suggested 20 experimental runs to carry work with ratable design concept shown in Table 1.

Table 1. Experimental Work and results work

Sr. No	Single Layer Height (mm)	Nozzle Distance (mm)	Scale factor	Yield Strength (N/mm <sup>2</sup> )	Feel rate
1	16	15	0.7	1.49	7
2	23	15	0.7	1.52	6
3	16	18	0.7	1.46	8
4	23	18	0.7	1.53	6
5	16	15	1.4	1.42	7
6	23	15	1.4	1.61	7
7	16	18	1.4	1.56	6
8	23	18	1.4	1.58	6
9	12.5	16.5	1.05	1.45	8
10	26.5	16.5	1.05	1.6	5
11	19.5	13.5	1.05	1.47	5
12	19.5	19.5	1.05	1.58	8
13	19.5	16.5	0.35	1.45	9
14	19.5	16.5	1.75	1.53	5
15	19.5	16.5	1.05	1.47	7
16	19.5	16.5	1.05	1.48	6
17	19.5	16.5	1.05	1.46	7
18	19.5	16.5	1.05	1.46	7
19	19.5	16.5	1.05	1.47	7
20	19.5	16.5	1.05	1.45	7

### III. RESULT AND EXPERIMENTAL WORK ANALYSIS

Following Table 2 shows analysis of variation for measurable yield strength on UTM machined.

Table 2. Analysis of Yield strength response for prototypes

Source	Sum of Squares	DF	Mean Square	F-value	p-value	
<b>Model</b>	0.0536	9	0.0060	6.71	0.0032	significant
A-Layer Hight	0.0233	1	0.0233	26.20	0.0005	significant
B-Nozzle Distance	0.0060	1	0.0060	6.77	0.0264	significant
C-Scale	0.0068	1	0.0068	7.67	0.0198	significant
AB	0.0021	1	0.0021	2.38	0.1539	
AC	0.0015	1	0.0015	1.70	0.2210	
BC	0.0021	1	0.0021	2.38	0.1539	
A <sup>2</sup>	0.0071	1	0.0071	8.01	0.0178	significant
B <sup>2</sup>	0.0071	1	0.0071	8.01	0.0178	significant
C <sup>2</sup>	0.0016	1	0.0016	1.84	0.2044	
<b>Residual</b>	0.0089	10	0.0009			
Lack of Fit	0.0083	5	0.0017	15.14	0.0049	significant
Pure Error	0.0006	5	0.0001			
<b>Cor Total</b>	0.0625	19				

The Model F-value of 6.71 implies the model is significant. There is only a 0.32% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, A<sup>2</sup>, B<sup>2</sup> are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The Lack of Fit F-value of 15.14 implies the Lack of Fit is significant. There is only a 0.49% chance that a Lack of Fit F-value this large could occur due to noise. Figure 1 shows normal probability plot.

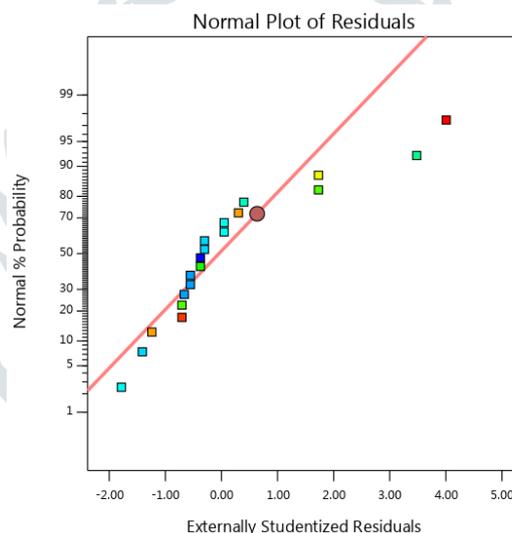


Figure 2. Normal Probability Plot

Figure 2 shows normal probability plot for yield strength of concrete deposition. Normal Probability plot is drawn for studentized residuals to check for normality of residuals. It used to evaluate the normality of response data. Residuals are the difference between the observed values and predicted values. If approximately follows a straight line indicate that the residuals are normally distributed. The points in the plot of residuals are significantly dispersed from straight

Table 3 Standard Deviation of model development

Std. Dev.	0.0298	R <sup>2</sup>	0.8580
Mean	1.50	Adjusted R <sup>2</sup>	0.7302
C.V. %	1.98	Predicted R <sup>2</sup>	0.0160
		Adeq Precision	8.7786

The Predicted R<sup>2</sup> of 0.0160 is not as close to the Adjusted R<sup>2</sup> of 0.7302 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs shown in Table 3. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 8.779 indicates an adequate signal. This model can be used to navigate the design space.

Table 4. Coefficients in Terms of Coded Factors

Factor	Coefficient Estimate	Df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	1.47	1	0.0119	1.44	1.50	
A-Layer Hight	0.0381	1	0.0074	0.0215	0.0547	1.0000
B-Nozzle Distance	0.0194	1	0.0074	0.0028	0.0360	1.0000
C-Scale	0.0206	1	0.0074	0.0040	0.0372	1.0000
AB	-0.0163	1	0.0105	-0.0397	0.0072	1.0000
AC	0.0137	1	0.0105	-0.0097	0.0372	1.0000
BC	0.0162	1	0.0105	-0.0072	0.0397	1.0000
A <sup>2</sup>	0.0168	1	0.0059	0.0036	0.0301	1.08
B <sup>2</sup>	0.0168	1	0.0059	0.0036	0.0301	1.08
C <sup>2</sup>	0.0081	1	0.0059	-0.0052	0.0213	1.08

The coefficient estimate represents the expected change in response per unit change in factor value when all remaining factors are held constant. The intercept in an orthogonal design is the overall average response of all the runs. The coefficients are adjustments around that average based on the factor settings. When the factors are orthogonal the VIFs are 1; VIFs greater than 1 indicate multi-colinearity, the higher the VIF the more severe the correlation of factors. As a rough rule, VIFs less than 10 are tolerable shown in Table 4.

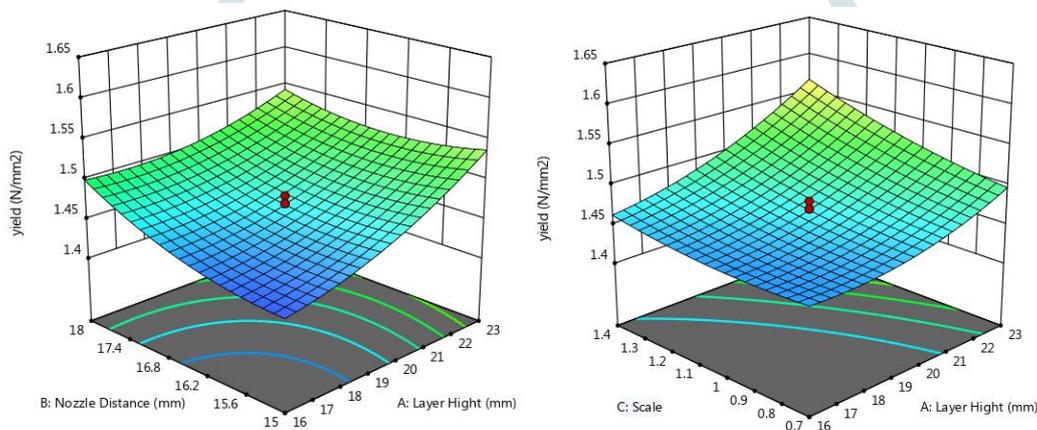


Figure 3. 3D Surface contour plots for yeild strength

Figure 3 shows 3D surface contour plot for response effect of concrete model testing on UTM machine. The yield strength of stacked concrete material is increases with increase in layer height. Scaling factor significantly not affected on yield strength due to hard segregated nature of concrete. Nozzle diameter and deposition rate has observed significant effect on yield strength of concrete for homogeneous deposition in bulk volume simultaneously. From the combine effect of surface graph, it can conclude that layer height of deposition and nozzle diameter directly proportional to yield strength in deposited material layer. Increase in layer thickness give good deposition property.

Table 5. ANOVA for Feel rate

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	21.34	13	1.64	11.40	0.0035	Significant
A-Layer Hight	4.50	1	4.50	31.26	0.0014	Significant
B-Nozzle Distance	4.50	1	4.50	31.26	0.0014	Significant
C-Scale	8.00	1	8.00	55.58	0.0003	Significant
AB	0.1250	1	0.1250	0.8684	0.3874	
AC	1.13	1	1.13	7.82	0.0313	Significant
BC	1.13	1	1.13	7.82	0.0313	Significant
A <sup>2</sup>	0.2078	1	0.2078	1.44	0.2748	
B <sup>2</sup>	0.2078	1	0.2078	1.44	0.2748	
C <sup>2</sup>	0.0292	1	0.0292	0.2030	0.6681	
ABC	0.1250	1	0.1250	0.8684	0.3874	
A <sup>2</sup> B	3.06	1	3.06	21.28	0.0036	
A <sup>2</sup> C	3.06	1	3.06	21.28	0.0036	
AB <sup>2</sup>	0.5625	1	0.5625	3.91	0.0954	
AC <sup>2</sup>	0.0000	0				
B <sup>2</sup> C	0.0000	0				

BC <sup>2</sup>	0.0000	0				
A <sup>3</sup>	0.0000	0				
B <sup>3</sup>	0.0000	0				
C <sup>3</sup>	0.0000	0				
<b>Residual</b>	0.8636	6	0.1439			
Lack of Fit	0.0303	1	0.0303	0.1818	0.6875	not significant
Pure Error	0.8333	5	0.1667			
<b>Cor Total</b>	22.20	19				

The Model F-value of 11.40 implies the model is significant. There is only a 0.35% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, AC, BC, A<sup>2</sup>B, A<sup>2</sup>C are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The Lack of Fit F-value of 0.18 implies the Lack of Fit is not significant relative to the pure error. There is a 68.75% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit shown in Table 5.

The Predicted R<sup>2</sup> of 0.6665 is not as close to the Adjusted R<sup>2</sup> of 0.8768 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs.

Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 12.601 indicates an adequate signal shown in Table 6. This model can be used to navigate the design space.

Table 6 Standard deviation and fits values for feel rates

Std. Dev.	0.3794	R <sup>2</sup>	0.9611
Mean	6.70	Adjusted R <sup>2</sup>	0.8768
C.V. %	5.66	Predicted R <sup>2</sup>	0.6665
		Adeq Precision	12.6015

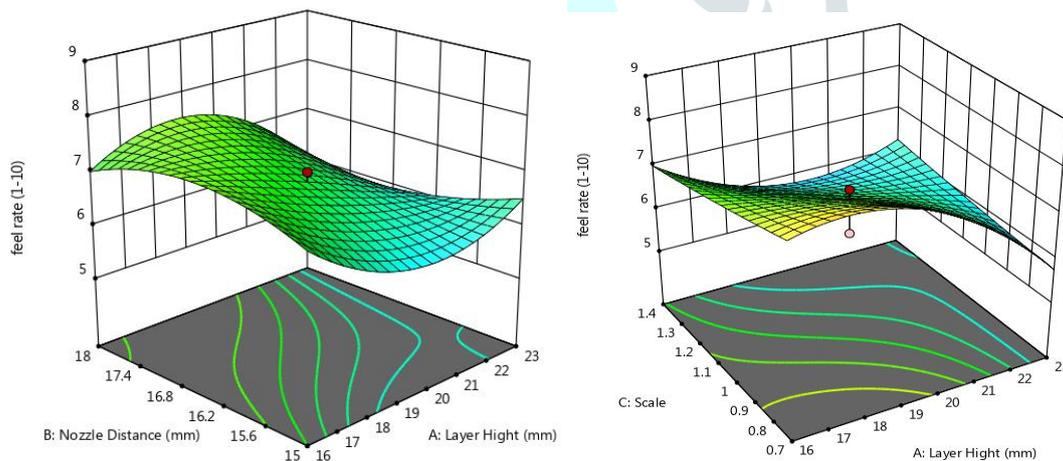


Figure 4. 3 D surface contour plots for feel rate of concrete deposition

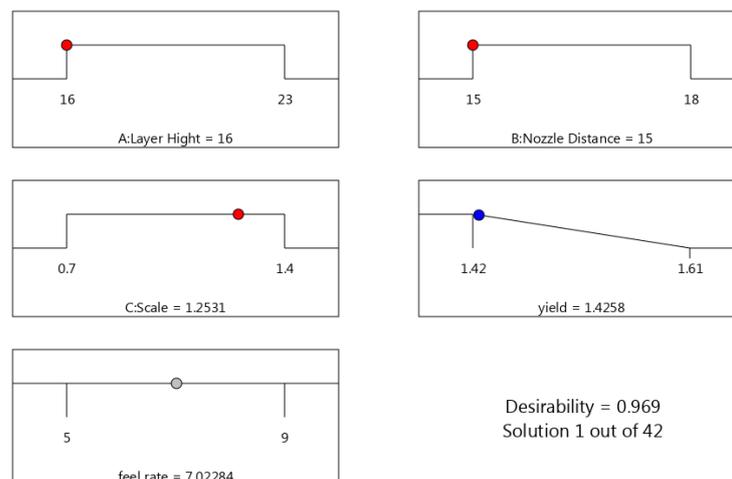


Figure 5. Desirability of Model prototype for higher yield

Figure 4 shows 3D surface contour plots for feel rate of appearance of Concrete prototype model shows different effect of fill rate at different layers deposition and ejecting nozzle diameters.

Desirability approach is most important for resultant output finding. It highlighted effective required result with better prediction of results. This results are helpful for comparison of output value. Desirability approach provided better solution for deposition of concrete in prototype model shown in figure 5 . Following desirability plots represents the highest yield strength of prototype model in testing machine.

#### IV. Conclusion

Concrete prototyping is new approach used to manufacture bulk prototype in different scale sizes. It becomes economical and fast deposition simple method of additive rapid prototyping method. Simple shape prototype made through direct deposition of concrete to mould through nozzles. Experimental work has performed using variation of deposition layer, nozzle diameter, scaling factor for deposition. Yield strength and appearance feel rate has checked for better improvement in concrete deposition methodology. Layer deposition and diameter of nozzle found effective in deposition method. This paper developed ideology for manufacturing of 3D printed concrete model by Additive manufacturing technology using response surface method. Fibre reinforced cavity is used to give shape to the model which helped to increase strength and increase dimensional accuracy product. Layer deposition and nozzle diameter are more important factor found for deposition rate and has more impact on yield strength. Smaller layer deposition observed poor performance in appearance of model. It given poor texture on model product and low yield strength.

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