The Effect of Admixture on Mortar in 3D Printing Technology

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Abstract. Mortar is made from a mixture of sand, cement and water. In order to obtain good extrude results for the application of 3D printing technology, in this research, mortar was added with admixture materials. There are two types of admixture in mortar, those are chemical admixture and pozzolan admixture. The highest compressive strength was obtained from Mortar+Pozzolan of 37.5 MPa, while the best flowtable and the best results from the extrude of 3D printing machine was Mortar+Chemical+Pozzolan.

Keywords: mortar, extrude, chemical, pozzolan

1. Introduction

The technology of 3D printing is currently developed to increase productivity in the sector of construction so that the infrastructure and building (housing, commercial, and industry) can be faster and more efficient. Compared to traditional building construction technology, the application of 3D printing process technology in construction has several advantages, including reducing the construction time by 50-70%, reducing construction costs by 10-30%, being able to make the construction of buildings with high complexity which is difficult to be done by traditional building construction technology, reducing construction costs by 10 – 30%, reducing the number of labor, reducing the risk of work accidents, and simultaneously reducing building waste so that it is environmentally [1].

Therefore, the construction of 3D Printing can be a solution to several problems, including construction costs, labor, construction speed, security, and the ability to make various shapes.

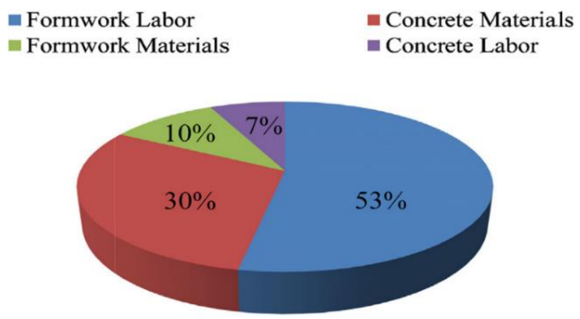


Figure 1. Typical cost distribution for new concrete construction project

The 3DCP process is divided into two segments (**Figure 2**) :

1. Software segment : 3D software such as AutoCAD is used to make the object model, which is then exported to the other software for the slicing process (defining the layer dimension). After that, the program file in the form of G-code produced all objects for 3D printing machine to read and conduct the job
2. Hardware segment: printer is integrated with the material delivery system connected to pump and pipe/ hose needed to send the material to nozzle. Printer and pump controller adjusted to the design is also further necessary.

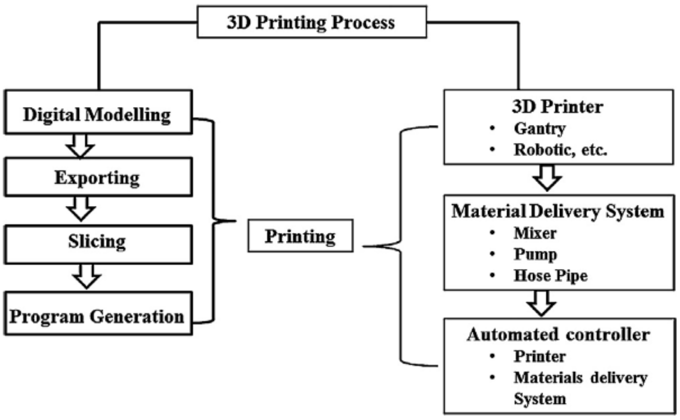


Figure 2. The process of 3D printing for construction industry

According to [2], the materials constructing the mortar are cement, water, and fine aggregate. However, the making of mortar which only consists of these three materials does not meet the characteristics of mortar according to the 3D printing machine, thus additional materials are needed. Mortar 3D printing must meet the printability characteristics which is the ability of fresh mortar to flow in and out of the machine and be able to form layer by layer which will form an object. Mortar that can be used on 3D printing machines must have printability characteristics consisting of several requirements, including flowability, extrudability, and buildability, and have high compressive strength. Meanwhile, the calculation of mix design to determine the needs of each material was obtained through trial and error using the Absolute Volume method.

Flowability characteristics can be fulfilled if the fresh mortar can flow in the 3D printing machine towards the nozzle without any inhibition. Meanwhile, the extrudability characteristics can be fulfilled if the mortar can be removed from the nozzle of the 3D printing machine. 3D printing mortar that is able to be printed vertically, able to maintain its shape after leaving the machine, and able to withstand the load of the mortar on it to prevent deformation is considered to have fulfilled the buildability characteristics. Based on the measurement of slump and slump flow of mortar using OPC cement, silica fume, fly ash, and river sand, current research obtained 3D printing areas with slump values between 4-8 mm and slump flow values between 150-190 mm giving a smooth and high buildability [3].

The mortar composition of the present invention needs additional materials to fulfill the needs of 3D construction printing process machine. Furthermore, the calculation of the mixed design to determine the needs of each material was obtained through calculations using the Absolute Volume method.

2. Methods

2.1 Research site

Testing and implementation as well as trial and error was conducted at the Laboratory of Materials, Universitas Gadjah Mada, Yogyakarta.

2.2 Data Collection Method

Research data were collected by reviewing the literature and conducting several experiments in the Materials laboratory of Universitas Gadjah Mada, Yogyakarta. The objective of studying literature review and conducting the experiments in the laboratory is to collect relevant data that were going to be applied in this research.

2.3 Mix Design

The design of the mortar mixture was conducted by applying the absolute volume method. Material used in designing the mixture composition needs special attention. The resulting 3D-printed mortar mix must be able to easily flow in and out of the nozzle, then once it can be extruded, the 3D-printed mortar material can have layer-by-layer buildability. The method used to determine the needs of each material is the calculation of the Absolute Volume method. According to the literature [4] the principle of this method is to determine the proportion of weight or volume of water, cement, and fine aggregate with a ratio of the volume of cement: sand: water is 1: s: w. Furthermore, this study used additives so that the equation becomes :

$$\frac{W_w/1000}{G_w} + \frac{(W_c - W_{a1})/1000}{G_c} + \frac{W_s/1000}{G_s} + \frac{W_{a1}/1000}{G_a} + \frac{W_{a2}/1000}{G_a} = 1 \quad (1)$$

Nomenclature **:**

w_w	= the need of water weight per cubic meter	G_w	= specific gravity of water
w_c	= the need of cement weight per cubic meter	G_c	= specific gravity of cement
w_{a1}	= the need of additive,1 weight per cubic meter	G_{a1}	= specific gravity of additive,1
w_s	= the need of sand weight per cubic meter	G_s	= specific gravity of sand
w_{a2}	= the need of additive,2 weight per cubic meter	G_{a2}	= specific gravity of additive,2

2.4 Flow table test

This test was conducted aiming to find out the percentage of the mortar distribution used to achieve ideal conditions. The equipment used is spread table, caliper, leveler, and tray. The implementation was done by preparing the mortar, measuring the top and bottom diameters as well as the height of the spreading ring to be used, putting the mortar into the spread table ring until it is full, and level the surface by using a leveling knife and trying to avoid any cavities in the ring of the spread table. Before the spread table is run, lift the ring from the mortar so that there is only mortar on the spread table. After that, the machine was run for 25 beats (±15 seconds). When it completed, the diameter of the mortar was measured again after the engine is run to record how much spread occurred.

Figure 3. The equipment and result test flowability

2.5 Experiment on 3D printing process

After mortar with a spread value ranging from 150 – 190 mm [5] was obtained, it was then continued by an experiment on a 3D printing machine, which is by pumping the mortar into the 3D printing machine to know whether the mortar can be extruded.

2.6 Compressive Strength Test

Compressive strength of the mortar is the maximum force per unit area which has the functions of working on a cube-shaped mortar specimen with a certain size and a certain age [6]. The compressive strength of mortar is significantly affected by the proportion of the mixture. In addition, water also affects the compressive strength of mortar. The lower the water-cement factor, the higher its compressive strength. However, the low water-cement factor can also decrease the workability.

The stages of the process of making the mortar composition used for 3D printing construction is the process of testing the compressive strength. According to [6] the compressive strength of mortar can be determined by the formula :

$$f'_c = \frac{P}{A} \qquad (2)$$

In the above equation, f'_c is compressive strength (MPa), P is maximum force (N) and A is unit area, mm^2.

3. Results and Discussion

3.1 The analysis results of specific gravity and unit weight of the material

Tabel 1. Specific gravity and unit weight (kg/m^3)

Material	Specific gravity	unit weight
Water	1,00	1,00
Cement	3,15	1,25
Sand	2,74	1,33
Additif 2	2,20	0,65
Additif 1	1,17	1,17

The results of the examination of the sand have met the standard specifications of SNI 03-1970 (specific gravity) and SNI 03-4804-1998 (unit weight).

3.2 Composition of mortar mix and mortar flowability test

Method used to determine the needs of each material is Absolute Volume method. Based on the research results, it was found that the largest flowability was mortar mixed with chemical admixture and pozzolanic admixture. This is in accordance with the purpose of each additive that the flowability results range in the given range [3] of 150 – 190 mm

3.3 Result of 3D printing process machine

All mix designs can be extruded via a 3D printing machine. According to the results of visual observations of the 4 types of mortar, the best 3D printing machine extrude is the mortar with a mixture of both admixtures (**M1,2**).

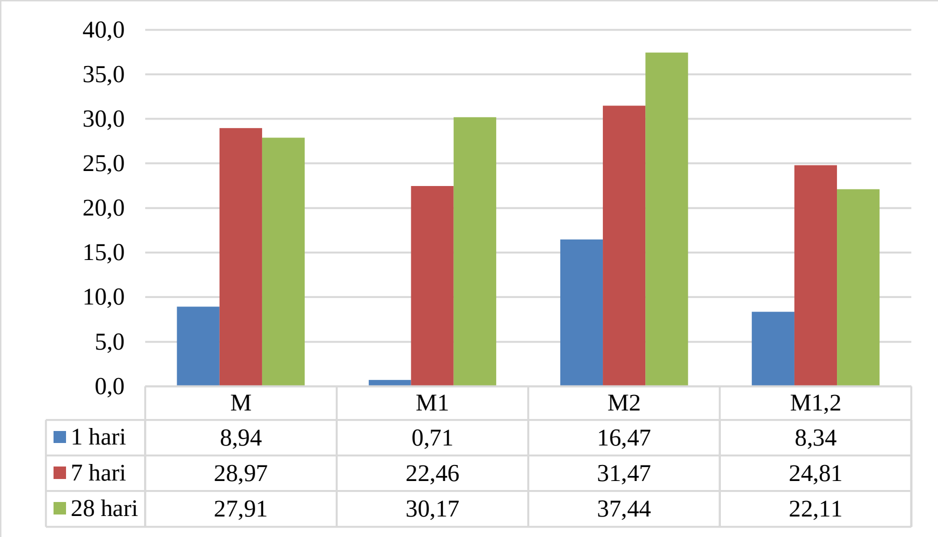
Figure 4. Testing mortar mix with a 3D printing machine

3.4 Result of mortar compressive strength test

The compressive strength of mortar can be determine using equation 2. The required data were the cross-sectional area (A = P x L) and the maximum load of the test results (P_{maks}). The calculation results of the compressive strength of concrete in this study can be seen in the following Table 2.

Table 2. Mix design mortar

Code	Object Size (mm)			A (mm²)	P_{maks} (N)	Compressive (MPa)	
	P	L	T			f'_c	f'_{cr}
Ma-1	50,0	48,0	51,0	2400,00	23000	9,583	8,938
Mb-1	50,0	48,0	51,9	2400,00	23000	9,583	
Mc-1	50,0	49,7	50,0	2485,00	19000	7,646	
Ma-7	50,0	51,0	51,0	2550,00	65000	25,490	28,974
Mb-7	51,2	49,4	50,6	2529,28	78000	30,839	
Mc-7	51,3	49,7	50,3	2549,61	78000	30,593	
Ma-28	50,8	49,5	50,0	2514,60	79000	31,417	27,905
Mb-28	51,0	49,6	50,4	2529,60	67000	26,486	
Mc-28	50,0	49,2	51,0	2460,00	63500	25,813	
M1a-1	50,0	49,5	53,0	2475,00	1500	0,606	0,713
M1b-1	50,3	50,0	52,0	2515,00	1500	0,596	
M1c-1	50,0	48,0	52,0	2400,00	2250	0,938	
M1a-7	50,3	54,2	50,1	2726,26	62000	22,742	22,463
M1b-7	51,8	49,4	50,0	2558,92	65000	25,401	
M1c-7	52,8	49,2	49,8	2597,76	50000	19,247	
M1a-28	50,0	47,4	52,6	2370,00	65000	27,426	30,175
M1b-28	50,0	47,4	52,0	2370,00	76500	32,278	
M1c-28	50,0	46,4	49,6	2320,00	71500	30,819	
M2a-1	50,0	50,0	51,0	2500,00	42000	16,800	16,469
M2b-1	50,7	50,0	51,7	2535,00	43000	16,963	
M2c-1	50,0	50,5	51,0	2525,00	39500	15,644	
M2a-7	50,5	50,3	50,5	2540,15	84000	33,069	31,473
M2b-7	51,0	50,0	50,0	2550,00	83000	32,549	
M2c-7	50,0	50,0	50,0	2500,00	72000	28,800	
M2a-28	51,4	50,4	50,3	2590,56	88000	33,969	37,435
M2b-28	50,7	50,5	50,5	2560,35	92500	36,128	
M2c-28	50,0	50,7	50,0	2535,00	107000	42,209	
M1,2a-1	50,5	50,2	49,1	2479,55	22500	9,074	8,344
M1,2b-1	50,5	50,4	49,8	2514,90	17500	6,959	
M1,2c-1	50,2	50,3	49,8	2499,96	22500	9,000	
M1,2a-7	48,7	50,3	50,0	2435,00	60000	24,641	24,807
M1,2b-7	50,8	50,2	50,8	2580,64	57500	22,281	
M1,2c-7	48,8	50,0	50,3	2454,64	67500	27,499	
M1,2a-28	48,9	50,1	49,8	2435,22	56000	22,996	22,107
M1,2b-28	49,5	50,0	50,0	2475,00	62500	25,253	
M1,2c-28	49,7	49,1	50,1	2489,97	45000	18,073	



	M	M1	M2	M1,2
1 hari	8,94	0,71	16,47	8,34
7 hari	28,97	22,46	31,47	24,81
28 hari	27,91	30,17	37,44	22,11

Figure 5. Mortar compressive strength test results

Based on Figure 5, it can be seen that the highest compressive strength of the concrete is in the composition of **M2** mortar mixture, in which the mortar is added with pozzolanic material. This can be well-understood because pozzolanic additives increases the durability and the compressive strength of the concrete. This causes the pozzolanic to react with the by-product of the cement hydration process, which is free lime (C_aOH_2), and further form CSH. Since it can react like cement, pozzolanic is also commonly referred to as cementitious.

4. Conclusion.

Based on the results obtained in the current research, it was discovered that the highest flowability was obtained when the mortar was mixed with both chemical additives and pozzolanic additives.

This was in accordance with the purpose of each added material. The highest compressive strength was found in the test object with **M2** code in the mortar which increases with the addition of additives. This is because the mortar compaction process was getting better. The use of admixture in mortar has an optimum value. In this study, the optimum value was achieved when the pozzolan additives were added.

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