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A Study of An Alternative Material For 3D Printing in Building Construction

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Abstract: Currently, 3D printing technology in the construction industry is growing in line with the era of the Industrial Revolution 4.0. Finding alternative and suitable materials for 3D printing that is more local in nature is a priority of the local construction industry. This study was conducted to assess the characteristics, properties and evaluate the suitability of new materials for use in 3D printing in construction. Three samples were prepared by mixing PU foam with fine sand. PU foam is used as a binder with a mixture ratio of 1:1 for each of Part A and Part B foam solutions. This material has been mixed with fine sand weighing 200 g, 300 g and 400 g respectively. Subsequently the mixture of this material was put into the mold and the time for the expanding and hardening of the material was recorded. The results of the study found that the three samples showed good flow properties and the time recorded by the three samples to harden was within 30 seconds, 35 seconds and 40 seconds. These results indicate that the use of PU foam as a binder material mixed with fine sand has the potential to be used as a material for 3D printing machines.

Keywords: 3D Printing, Construction Material, PU Foam

1. Introduction

Nowadays, the new technology of 3D printing of buildings for sustainable houses of the future are introduced. This technology is already used in China and Dubai. It is an invention of 3D printer for new construction technique. It is the latest revolution of construction technology that have many advantages for the construction industry and for the development. 3D printing is an additive manufacturing that consist of process of making three-dimensional solid object from a digital file. The requirement for the construction industry is increasing to fulfill the needs of industries in Malaysia. An innovation should be included so that we can evolved with the development of technologies. Due to the demand for construction are increasing in terms of material, complexity and multi-functionally and smart material [2][9]. Application of 3D printing in building construction has many advantages such as:

i. Construction cost can be reduced by eliminating the formwork

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ii. By eliminating the dangerous work, injury rates can be reduced that can increased the safety level in construction.

iii. Create a high-end technology-based jobs.

iv. By operating at a constant rate can reduces onsite construction time.

v. Can minimized the errors using precise material deposition.

vi. Can reduce waste such as formwork which can increase the sustainability in construction.

The usage of PU FOAM as a complex wall by using 3D printing technology in construction industries are increasing. The technique used to apply the PU foam is through Batiprint3D technique. Polyurethane foams are derived from polymeric foams which used extensively in wide range of applications of disposable packaging and cushioning to insulation and construction. The market of PU foams is increasing since 2014. The production of the PU product in the Asia Pacific region was approximately 11.5 million tons in 2014 and increasing to over 15.5 million by 2019 with 6.20 % annual average growth rate which causing major concern for environmental protection. The PU foam are produced from the derivation of various polyols and polyisocyanate as the raw material. The raw material for PU foam are derived from petroleum. However, to satisfy the concern of limited resources and the environmental concern. The PU foam are using vegetable oil as the raw material. Because vegetable are renewable sources [1][7][8][10].

This study objectives are to study the characteristic of the material that suitable for 3D printing and to study the properties of the alternative material that can be used as the substitute material for concrete 3D printing. Due to expansive raw material of concrete printing, the application of the 3D printing technologies facing some challenges. To overcomes the challenges that the construction industries may facing, therefore this study are conducted along with the testing of the material.

2. Materials and Methods

The material and method of this study are based on the past research and the parameters which correspond to the characteristic of the 3D printing technique. Based on the objectives of the study which is to study the parameter of flowability and workability of mixture that consist of fine sand and alternative material chosen (PU foam).

2.1 Materials

The main materials that are used in this study are find aggregate (sand) and the binder materials are Polyurethane Foam. The rest are listed below.

- Polyurethane Foam (PU foam)
- Fine Sand
- Measuring cup
- Weighing scale
- Hand mixer
- Mould (Dimension 30 cm x10 cm x 20 cm)

2.2 Methods

The testing method are conducted to test whether the combination of PU foam and fine sand can create a new alternative material for 3D printing. The mixture need to be flowable and can stiffen in a

shorts time. Correspond to the characteristic of the 3D printing machine. The material of the 3D printing has to be extruded based on extrusion rates which is in the range of 50 mm/s to 500 mm/s [4].

2.2.1 Procedure

The procedure has been designed as per Figure 1 below in order to meet the objectives of these study.

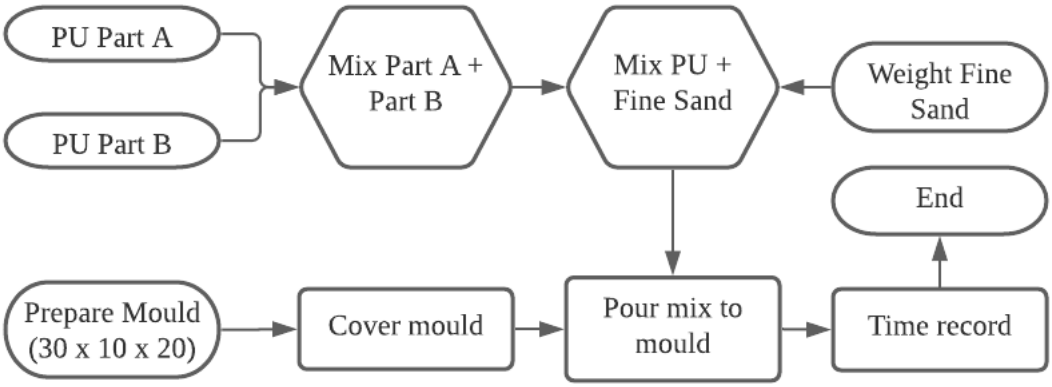

Figure 1: Experimental flowchart

The details procedure that has been designed are as below:

1. The mould for the mixture are formed in dimension of 30 cm x 10 cm x 20 cm by using wood board.
2. The mould are wrap with plastic layer so that the mixture does not stick to the mould and make it difficult to pull out the block.
3. The weight of fine sand are measured with weighing scale for 3 sample which are 200 g, 300 g and 400 g.
4. According to manufacturer ratios the PU liquid are mix in 1:1 ratio. Hence the PU liquid used are 100 ml respectively for Part A and Part B.
5. For the first sample the amount of the fine sand used is 200 g, then the fine sand are mix with the PU liquid Part A.
6. Then, the PU liquid Part B are poured into PU liquid Part A and mix quickly before added into the mould. After that we have to wait for the mixture to fully expanded
7. The mould have to be closed tightly so that the mixture will not leak and to ensure that the pressure in the mould can form a strong block.
8. The time taken for the mixture to fully expand and hardened are recorded.
9. After the block are form, the block are pulled out from the mould and the strength of the block are tested by stepping on it.
10. The procedures are repeated with the different amount of fine sand which are 300 g and 400 g.

For building construction strength of the building are importance to withstand the load. In order to produce a stronger block, fine sand are used to fill the pores produces by PU foam. Hence the amount of the fine is different to determine which amount are suitable to be use.

3. Results and Discussion

After experimental works are conducted to prove whether this study can achieve the objectives. Three objectives are used as a guide for this research which are to study the characteristic of the of material that suitable for 3D printing. Next, to study the properties of the alternative material that can be used as the substitute material for 3D concrete printing. Lastly, to evaluate the parameter of flowability and workability of mixture consist of fine sand and alternative material chosen.

3.1 Results

3.1.1 Characteristic of the material for 3D printing technology.

To achieve the first and second objectives of the study which is the characteristic of the material that are suitable for 3D printing are obtained through literature review of the past research. It is important because the suitability of the material is depending on the existing material of the 3D printing. The material for 3D printing needs to be able to be extruded through the nozzle. Hence, the material have to be in paste state which are able to flow and set within the 10 seconds until 1minutes. It is because based on the past research, the mixture will be printed layer by layer. In order to print the second layer and so on the first layer of the mixture need to be stiffen quickly. But the mixture must not lose its moisture. Because the layer need to have interlocking bond with each layer to increase the strength and stability. The interlocking will occur if there is moisture available in the mixture [6].

3.1.2 Flowability of the mixture.

To achieve the last objective of the study, the testing are carried out. The testing are conducted with three sample. Each sample have different amount of fine sand. Sample 1 using 200 g of fine sand, Sample 2 using 300 g of fine sand and Sample 3 using 400 g of fine. The purpose of using different amount of fine sand is to obtain the optimum concentration of the mixture. So that we can have most suitable ratios of the mixture. Hence based on the flowability of all sample, Sample 2 have the best flowability which can apply to concrete 3D printing. It is because Sample 2 has the most appropriate ratio and suitable towards our purpose. For sample 1 the mixture are fluidity, and the shape cannot be formed when applied to 3D printing machine. However, Sample 3 also have suitable flowability but sample 3 is not suitable for concrete 3D printing. It is because, the process of 3D printing are by printing the mixture layer by layer which need the moisture and a bit of fluidity. So that each layer can interlock by each other. If the mixture is dry and stiff quickly, the interlock of each layer cannot be happening [6]. The results are shown on Table 1 below.

Table 1: Flowability of the mixtures

No. of sample	Flowability of the mixtures when it is poured into mould.
1.	Flowable
2.	Flowable
3.	Flowable

3.1.3 Workability of the mixtures.

One of the characteristics of the 3D printing machine is the mixture are able to be hardened and another layer can be printed on the existing layer. The mixture need to have optimum strength so that the mixture can hold another layer that will be printed to form a wall. To examined which suitable ratio can formed a mixture that will produce a suitable block to build a wall, a simple test is conducted by preparing 3 sample [6]. The time taken for the mixture to be hardened are different due to amount of the fine sand. In addition, the expanding time of each sample are also different. The more amount of

the fine sand the more time are needed for the mixture to be hardened. The time taken for the mixture to be hardened are important because the 3D printing are using layering process to build or produce a product. Same goes for concrete 3D printing, the interlocking bond between the layer are needed. The results are shown on Table 2 below.

Table 2: Time taken for the mixture to hardened

No. of sample	Time taken by the mixture to hardened.
1.	30 seconds
2.	35 seconds
3.	40 seconds

3.1.4 Sample appearance

Sample 1 (refer to Figure 2), the block is smooth, and the appearance of the block are suitable for the wall. However, the strength of the block is low. It is because the amount of the fine sand are insufficient. The PU foam has pore after expanding to its maximum size, since the amount of the fine sand are insufficient. The pore in PU foam cannot be fully covered. Hence the strength of the block are also low when the block are stepped.

Figure 2: Sample 1 with ratio 1:1:1

Sample 2 (refer Figure 3), the block is a bit rough but mostly of the appearance are smooth. Sample 2 has the most suitable strength. It is because the ratio of the PU liquid and fine sand have perfectly fit each other. The strength of the block are increasing because the pore of the block are fully covered. In other words, fine sand act as aggregate to increase the strength of the cement.

Figure 3: Sample 2 with ratio 1:1:1.5

Sample 3 (refer Figure 4), the block is rough and produce sand debris when touched. However, Sample 3 are the strongest block when stepped. It is because the amount of fine are fully covered the pores and form a bond that makes the block stronger. But ratio for Sample 3 are not suitable to be applied in 3D printing machine. It is because after the mixture are stiffened the block forming sand debris. Which conclude that the amount of fine sand more than PU liquid mixture.

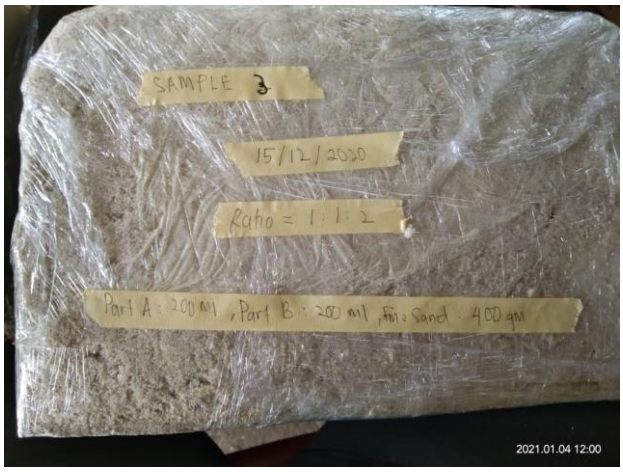

Figure 4: Sample 3 with Ratio 1:1:2

3.2 Discussion

The result of all sample are obtained through the experimental work to evaluate the parameter of flowability and workability of the mixture. For Sample 1, the mixture are able to flow, and the time taken for the mixture to be hardened is 30 seconds. Ratio of Sample 1 are not suitable because the mixture hardened too quickly and may not able to form the interlocking bond because the interlocking bond can occur if there is some moisture in mixture. In addition, the appearance and the strength of Sample 1 are not suitable to be applied in building construction. For Sample 2, the mixture are able to flow, and the time taken for the mixture to be hardened is 35 seconds. Ratio of the Sample 2 are suitable to be used as binder material in concrete 3D printing. It is because the interlocking bond can occur within the 35 seconds as the material are hardened. Even though the appearance of Sample 2 are it rough but it have higher strength compared to sample 1. Lastly, for Sample 3, the mixture are able to flow but a bit slowly it is because it have higher concentration as the sample 3 using 400 g of fine sand. The appearance and the strength of the Sample 3 are higher than sample 1 and Sample 2, however due to its flowability Sample 3 are not suitable in concrete 3D printing because the layering process cannot be done. In addition, the time taken for Sample 3 to be hardened is 40 seconds, hence the interlocking bond did not occur. As conclusion the most suitable binder material ratio for concrete 3D printing is Sample 2. However sample 1 and sample 3 ratios can also be used in concrete 3D printing with further research as sample 1 and sample respectively have advantages as a binder.

4. Conclusion

According to the findings of this research, PU foam as alternative material for 3D printing in building construction is the most suitable material considering all the objective are obtained. The application of PU foam as alternative material in building construction can create opportunity to enhances the usage of technology. However further research are needed to improve the strength and workability of the mixture. A solution to increase the strength of the block despite of using PU foam as the main material for 3D printing in building construction. A solution to maintain the pressure of the mixture in the mould after all the material are mixed. It is because the pressure of the mixture is high hence, it causes the mould to break down due to pressure push by the mixture during the PU foam are expanding

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