

The Effect of Microbes and Fly Ash to Improve Concrete Performance

Adlizie Rifkianda Muhammad¹, Januarti Jaya Ekaputri^{1*}, and Makno Basoeki²

¹Civil Engineering Department, FTSPK, ITS, Kampus ITS Sukolilo, Surabaya 60111, Indonesia

²Bioconc Center Foundation, Sidoarjo, Indonesia

* Corresponding author: januarti@ce.its.ac.id

(Received: September 18th 2021 ; Revised: October 19th 2021 ; Accepted: October 20th 2021)

Abstract: This paper presents the application of fly ash combining with microbes in concrete to reduce cement content. A class F fly ash as cement replacement was applied with ratios of 20%, 30%, 40%, and 50% to reduce hydration heat. Microbes from bacterial consortium were applied to increase concrete compressive strength. The concrete mix design from SNI 03-2834-2000 was applied for a compressive strength target of 30 MPa. The mechanical test was carried out consisting of compressive and tensile tests. Concrete workability and the heat of hydration measurement were performed for fresh concrete. The results showed that the maximum strength of 45.10 MPa was obtained from specimens with 30% fly ash content. Application of microbes associated with fly ash content of 40% showed the maximum strength of 48.47 MPa. It was found that the tensile strength also increased with the application of fly ash and microbes. Hydration temperature of concrete decreased with the increase of the ash content. This proves that the application of fly ash and microbes in concrete can reduce the cement as well as increase the concrete performance.

Keywords: Fly Ash; Concrete Compressive Strength; Microbes; Workability; Hydration Heat.

1. Introduction

Concrete is a material commonly used in building structures, roads, and bridges. It has sufficient strength to support the weight of a structure. Normal concrete is concrete that weighs up to 2200 - 2500 kg/m³ [1].

Infrastructure development in Indonesia using concrete is increasing rapidly. However, in concrete mix, cement is utilized greatly requiring high energy. It is also known that cement is a significant contributor to air pollution such as dust particles as well as CO₂ emissions. This makes cement become one of the factors causing global warming. To overcome this problem, concrete technology experts proposed cement replacement to materials increase strength, durability, more economical, and environmentally friendly. One of these efforts is replacing cement with fly ash and microbes application.

There are some results of fly ash replacement in concrete. The replacement of cement with fly ash can be used at 10% fly ash content of cement weight (657 kg/m³ of concrete) and the compressive strength increased as the fly ash content increased to 20%, 30%, and 40%. An optimal 28-day compressive strength of 122 MPa was achieved when 40% fly ash was applied [2]. Ready-mix concrete mixtures which cement was replaced with fly ash of 30-33% showed the same compressive strength results with normal concrete [3].

In Indonesia, there have been many studies on tensile strength of concrete containing fly ash. One of them was conducted by Marthinus, Sumajouw, and Windah [4]. They replaced cement weight (450 kg/m³ of concrete) with fly ash of 30%; 40%; 50%; 60%; and 70%. The maximum tensile strength of 3.21 MPa was achieved by 30% fly ash at 28 days. The lowest tensile strength of 0.82 MPa at 7 days, was given by specimens with 70% fly ash.

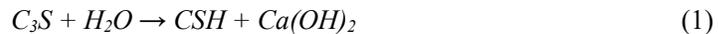
The effect of fly ash as cement replacement is to reduce the hydration heat. A study revealed that the exposure temperature at 150; 250; 350; 450; 500°C in fly ash concrete, resulted in reducing of corresponding temperature in the fly ash concrete in 85 minutes to 111; 172; 192; 248; and 321°C, respectively [5].

On the other hand, a concept of bio-cementing has been discovered as a new material in concrete called bio-concrete. *Bacillus megaterium* (30×10⁵ cfu/ml) mixed in fresh concrete increased the compressive strength of concrete up to 24% from 50 MPa to 64 MPa owing to deposition of CaCO₃ [6]. The compressive strength, split tensile strength and flexural strength of concrete were improved by using fly ash (10% by weight of cement) enriched by *Bacillus sphaericus*. The results were compared with control specimens, for compressive strength of 29.33 MPa to 32.50 MPa, split tensile strength from 3.2 MPa to 4.14 MPa, and flexural strength from 3.33 MPa to 3.5 MPa [7]. The use of fly ash enriched with *Bacillus sphaericus* can replace cement in concrete because economically, reduce CO₂ emissions and save electricity consumption in cement production. That states microbes can improve the quality of concrete, but microbes grow weaker against high temperatures. The growth of bacteria (ammonia-oxidizing bacteria) was very hampered by high temperatures, especially at temperatures over 40°C [8].

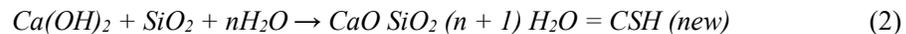
There is a link between fly ash and microbes in the concrete mixture to contribute in sustainable green infrastructures. The influence of microbes to the fresh concrete as well as the concrete performance as a benchmark of fly ash application in normal concrete is the main discussion in this study.

2. The mechanism of fly ash and microbes in concrete

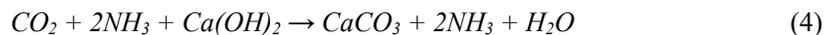
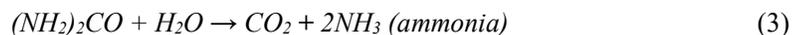
When the hydration reaction of the cement occurred, the C₃S minerals from cement reacts with water (H₂O) to produce calcium silicate hydrate (CSH) and Ca(OH)₂ as expressed in Eq. (1).



The result of the cement hydration reaction is CSH which is the adhesive material from the cement that build the concrete strength, while Ca(OH)₂ is a solution that fills pores in concrete. When fly ash with Ca(OH)₂ starts a pozzolanic reaction, it produces additional CSH that fills the concrete pores. It is presented in (Eq. (2)).



The mechanism of microbes increases the compressive strength of concrete. Microbes and water reacts in concrete, then produces ammonia and CO₂. Ammonia and CO₂ in the concrete pores react with calcium oxide (Ca(OH)₂) and produced calcium carbonate (CaCO₃) which settles in the concrete pores. These mechanisms are expressed in Eq. (3) and Eq. (4).



The two chemical reactions in Eq. (2) and Eq. (4) both reduced Ca(OH)₂ which is a solution located in concrete pores so that concrete pores were closed by calcium silicate hydrate (CSH) and calcite (CaCO₃). This causes a denser concrete.

3. Materials and Work Methods

3.1. Materials

3.1.1. Cement and Fly Ash

The cement used was Portland cement composite with a specific gravity of 2.98 gr/cm³. A class F Fly ash was selected from PT. Petrokimia Gresik, Indonesia with a specific gravity of 2.37 gr/cm³. Its chemical contents are listed in Table 1.

Table 1. Chemical content of fly ash

Oxides (% by mass)	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	Na ₂ O	SO ₃	TiO ₂	LOI
	46.61	23.31	6.77	14.45	1.27	1.70	0.54	1.55	0.79	3.80

3.1.2. Coarse aggregate and fine aggregate

Coarse aggregate was selected having maximum size of 20 mm with a specific gravity of 2.69 gr/cm³. River sand was selected for the fine aggregate with a specific gravity of 2.59 gr/cm³.

3.1.3. Superplasticizer

The superplasticizer used was Tancem 60 RP, as a substitute for water by reason of lower w/c in some mixtures. This superplasticizer includes admixture type F (high range water reducer) [9]. The recommended dose is 0.2% by binder mass.

3.1.4. Microbes

The microbial used was a bacterial consortium from Bioconc Foundation Center, Indonesia. Bioconc is a biotechnology product in the form of a liquid made from organic/natural ingredients, denatured proteins, polymers surfactants, and organic minerals that have been fermented by beneficial microbes [10]. It is not pathogenic and has a pH of 8.8. The dose used was 400 ml/m³ of concrete [11].

3.2. Work Methods

3.2.1. Mix Design

Indonesia standard for mix design was used for the compressive strength target at 28-days of 30 MPa. The water/binder ratio was limited at a minimum of 0.3 to guarantee the convenience of using fly ash in the job mix, and the mix design of 10 variations is listed in Table 2.

Table 2. Mix design of fly ash and microbial concrete per m³ of concrete

No	Code	Fly Ash (%)	Cement (kg)	Fly Ash (kg)	Water (kg)	Fine Agg. (kg)	Coarse Agg. (kg)	Microbes (0,4 L)	HRWR (kg)	W/B
1	0FA	0	387	0	205	943	871	0	0	0.53
2	20FA	20	367	92	167	859	935	0	0.92	0.42
3	30FA	30	389	167	163	794	913	0	1.11	0.37
4	40FA	40	415	277	158	734	844	0	1.38	0.32
5	50FA	50	395	395	154	695	799	0	1.58	0.3
6	0FAM	0	387	0	205	943	871	0.4	0	0.53
7	20FAM	20	367	92	167	859	935	0.4	0.92	0.42
8	30FAM	30	389	167	163	794	913	0.4	1.11	0.37
9	40FAM	40	415	277	158	734	844	0.4	1.38	0.32
10	50FAM	50	395	395	154	695	799	0.4	1.58	0.3

Note: xxFA = Percentage Fly Ash in Concrete; FAM = Concrete containing microbes.

3.2.2. Curing process

Specimens were cured at moist condition with covering the concrete with wet sacks or cloth. Moist curing was stopped 24 hours before mechanical testing conducted. It is well known that the strength of HVFA (high volume fly ash) concrete increased as well as decreasing of water permeability of concrete [12].

3.2.3. Manufacture and test of the specimen

The specimen was made in cylindrical molds with a diameter of 10 cm with a height of 20 cm and a cube mold (15x15x15 cm). The tests were divided into mechanical testing and fresh concrete testing. The mechanical tests were compressive strength and a split tensile strength test. Workability test and hydration heat monitoring were conducted for the fresh concrete.

4. Analysis and Discussion

4.1. Concrete compressive strength

The results of compressive strength at 28 days with variations of fly ash are presented in Fig. 1. The specimens with bacteria is illustrated in a red mark.

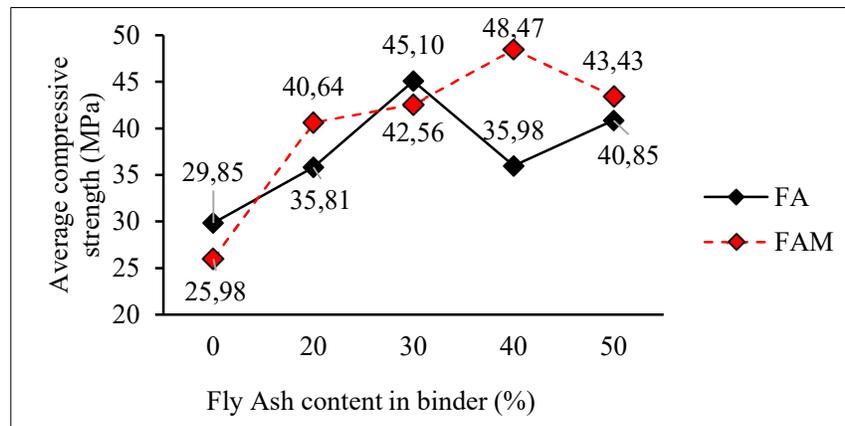


Fig. 1. The 28-day compressive strength with variations of fly ash

In Fig. 1, the use of fly ash in concrete increases the compressive strength and optimum variation of fly ash by 30%. Concrete strength at 28 days with 30% fly ash content (30FA) increased by 51% from control specimen (0FA). A study reported that replacement of cement with fly ash is 30% increased compressive strength by 15.6% [13]. Concrete strength at 28 days of age with 40% fly ash containing microbes (40FAM) increased by 62% from the control. Another study showed that concrete containing 10% fly ash with *Sporosarcina pasteurii* increased its strength of 20% as compared to the normal specimen [14]. In Fig. 1., the influence of microbes increases the ash content up to 40%, but in the 50% fly ash content, the influence of microbes was reduced, due to limited cement amount so that the availability of Ca(OH)_2 or portlandite reacted with fly ash and microbes. However, the influence of microbes on concrete without fly ash reduced the strength. The 28-day strength of specimen 0FAM decreased by 13% as compared to specimen 0FA. The decrease was likely caused by the weaken of microbes at high temperature during early hydration in the concrete. It is known that bacteria from *Sporosarcina pasteurii* produced urease enzyme was optimal in concrete at 25°C [15]. Bacterial growth (ammonia-oxidizing bacteria) was inhibited by high temperatures, especially at temperatures more than 40°C [8]. It is concluded that when the hydration temperature approaches 25°C, the urease enzyme

production becomes more optimum and if it exceeds 40°C, the urease enzyme production becomes hindered. Another report on the addition of *Bacillus megaterium* to concrete without fly ash increased the compressive strength of concrete up to 16.1% of the normal compressive strength of 33 MPa [16].

In Fig. 2., there is a significant increase in the compressive strength of concrete from the age of 3 days to 14 days. In general, steady strength started from the age of 21 days to the concrete age of 28 days showed by concrete without bacteria and fly ash. However, a tendency of strength increase after 28 days showed by bacterial specimens. It is in accordance with a study on fly ash concrete that the strength increased at the later age [17]. Pozzolanic reaction incorporating with the bio-cementation in concrete pores resulted in denser concrete at the later age. This mechanism is optimized at the bacterial specimens containing 30% fly ash.

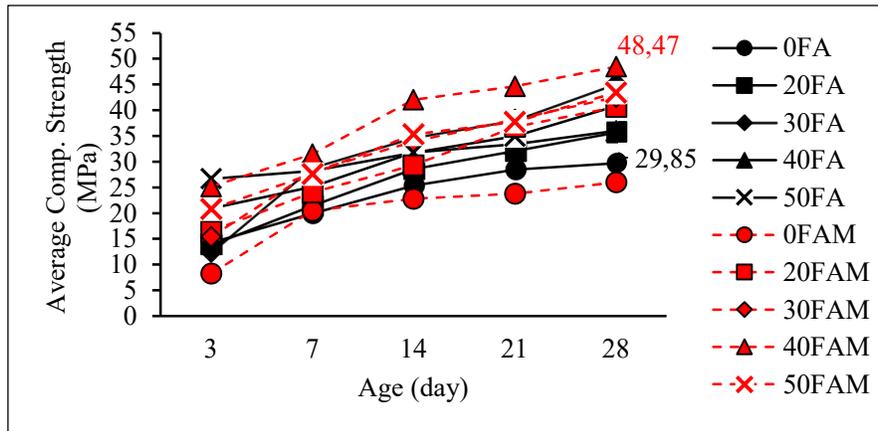


Fig. 2. Compressive strength of concrete with the variation of fly ash content

4.2. Concrete splitting tensile strength

The graph of the relationship of tensile strength to fly ash content is provided in Fig. 3. The red mark represents specimens containing microbes.

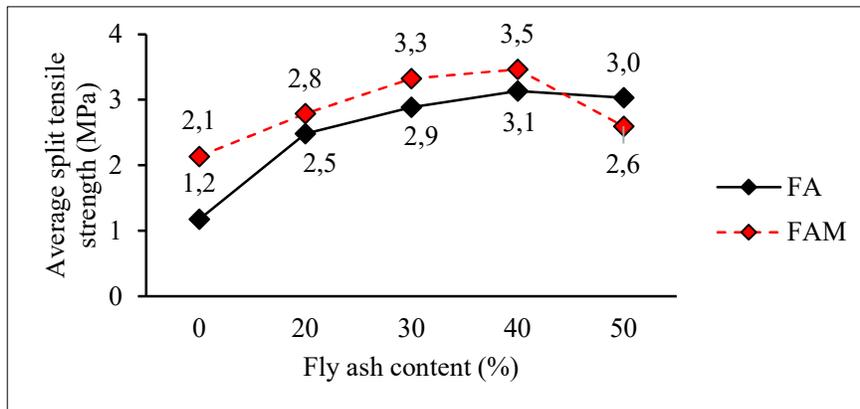


Fig. 3. Effect of fly ash content on the tensile strength

In general, all split tensile strength increases with the increasing of ash content. The maximum split tensile strength is shown by specimen 40FAM with a split tensile strength increased by 166% from control specimen. It was reported by a study that 25% fly ash in a mixture of self-compacting concrete (SCC) increased the tensile strength of concrete by 20.51% of control specimen

[18]. Another study on bio-concrete stated that the concrete fly ash 30% with microbes increased the tensile strength of 13.8% of fly ash concrete [19]. The filler effect of microbes revealed that it also influenced the tensile strength. This mechanism is also demonstrated by specimen 0FAM where the micro-filler effect of bacteria is effective. At the optimum point (40% fly ash), the tensile strength with microbes increased by 10.5% when compared to ordinary fly ash concrete. The concrete with 50% of fly ash containing microbes (50FAM) shows a tensile strength reduced by 16.9% from 50FA. This is influenced by of decrease of space for microbes in the concrete-filled with fine particles fly ash. Another explanation is in the mixture with 50% FA, cement content as the main binder in concrete was reduced.

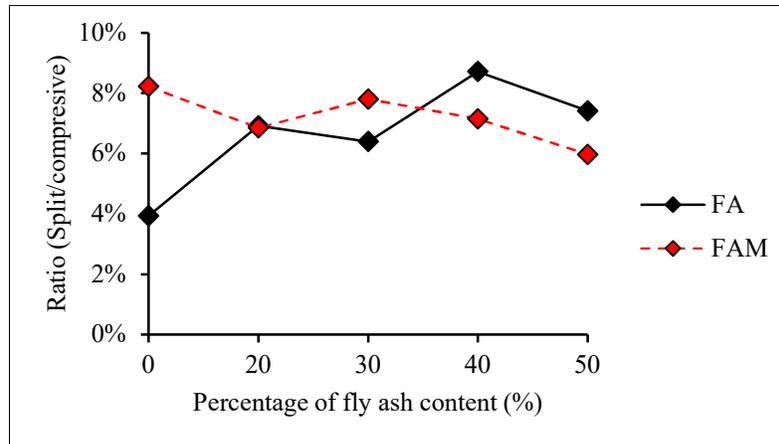


Fig. 4. Ratio of split to compression with variations of fly ash

In Fig. 4., the ratio between the split tensile strength and the compressive strength is presented. In specimen 40FA, a ratio of 8.7% is the maximum and the ratio decreases as the ash increased. It reveals that the effect of fly ash is more profound to the splitting tensile than the effect of bacterial precipitation. The effect of calcite sedimentation in concrete pores is generated first by bio-activation then followed intensively by the pozzolanic reaction.

4.3. Concrete Workability

The required slump in this study was in the range of 60-180 mm. Fig. 5. provides the slump results. As the density of fly ash is less than Portland cement, more cement substitution affected the volume of ash in the mixtures increased. In general, this is the reason that the addition of fly ash causes slump tends to decrease. The slump of mixtures with fly ash content in the range of 20%-40% decreases because very fine fly ash particles cause some of the water that was supposed to react with cement was also absorbed by fly ash during mixing. Some reports indicated that fly ash absorbed more water than cement because the fly ash particles has irregular and porous properties [20]. However, fly ash can increase workability in concrete with a fly ash content of 0% - 40% where it is different from addition of silica fume by 5% - 15% reduced slump in concrete [2, 21]. In some cases, fly ash is utilized as a superplasticizer admixture to increase the workability of concrete. The addition of microbes did not affect the value of slump in concrete. The increased slump was not caused by microbes but rather the effect was given by superplasticizer into the concrete.

In Fig. 5., the addition of fly ash requires more superplasticizer (HRWR). It was also reported that the use of fly ash varied at 25%, 35%, 45%, 55%, and 65% required a superplasticizer of 0.05%, 0.1%, 0.15%, respectively [22]. This is because of increased demand for cement as the w/b ratio was reduced. Surprisingly, the addition of microbes affected to the mixture more

workable. At 50% fly ash there is a significant increase in a slump because the concrete mix tends to become SCC (self-compacting concrete) due to excessive use of superplasticizer (0.41% of binder). This is consistent with the use of superplasticizer for making SCC concrete was equal to 0.3% of the binder caused. The superplasticizer inside the concrete created a temporary dividing layer between water and cement resulting in a hydration reaction cement occurred indirectly which makes the concrete mixture if it looks more flowable [23]. The effect of gas produced by microbes was found in specimens 0FAM and 20FAM. The gas created more spaces in the fresh mixtures and enhanced the slump [24, 25].

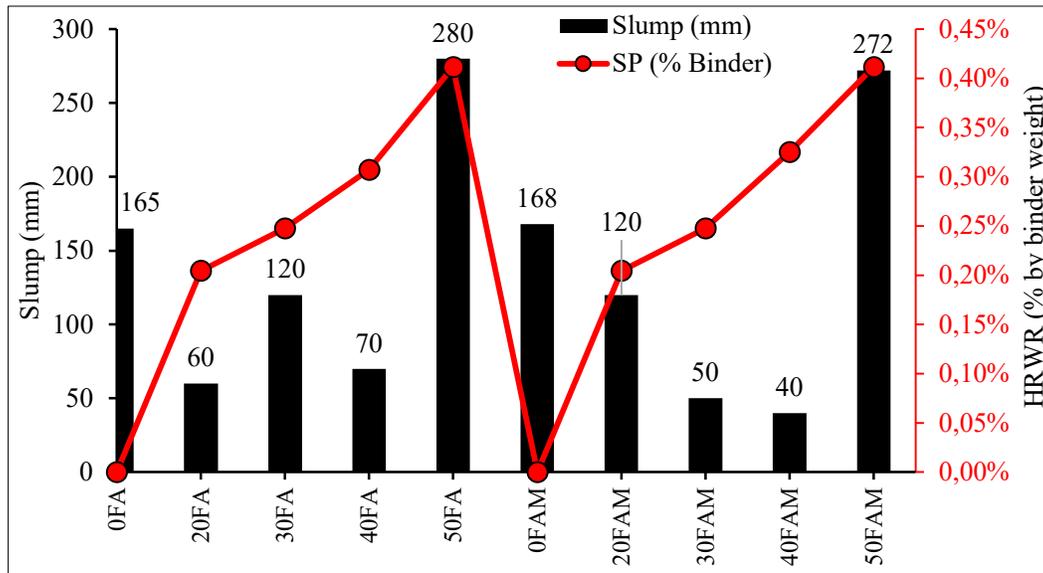


Fig. 5. The relation of the slump with the amount of superplasticizer in concrete

4.4. Concrete temperature measurement

The relationship of hydration temperature in 24 hours after casting is presented in Fig. 6. with the amount of cement is provided in each mark.

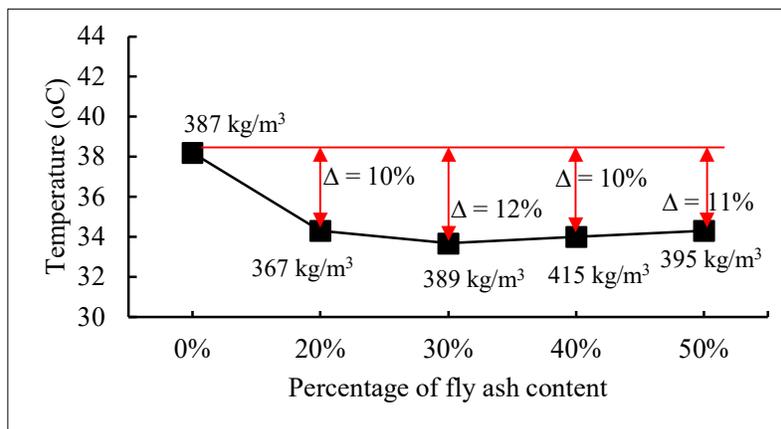


Fig. 6. The effect of fly ash content on hydration heat

The experiment is proposed by our previous study. The temperature of fresh concrete in cubical mold with a size of 15 cm was monitored using a thermocouple [26]. In this study, the 24 h

measurement using a data logger connected to a thermocouple cable that was inserted into the midpoint of the concrete. In Fig. 6., the use of fly ash in concrete reduces temperatures to 10% - 12% and the temperature started to decrease effectively by using 20% fly ash. and the peak decreased at 30% fly ash, after that the concrete temperature was almost same/constant. It was also reported that fly ash reduced temperature in fresh concrete from 45.2 °C to 34.5 °C with the application of 45% fly ash [27].

5. Conclusions

Based on the results of this study, the following conclusions can be drawn:

1. Fly ash and microbes have the same role to increase the compressive strength of concrete by filling pores concrete pores resulting in denser concrete. Concrete compressive strength at 28 days increased by 51% achieved by specimen 30FA. In addition, the use of microbes in specimen 30FAM increased the 28-day compressive strength by 62% from the control and increased by 11% from 30FA.
2. In the 50% variation of fly ash, the influence of microbes was reduced, due to the limited amount of cement so that the availability of $\text{Ca}(\text{OH})_2$ or portlandite which should react with fly ash and microbes also decreases.
3. The maximum split tensile strength was 40% fly ash concrete with the increase of 166% higher than the control. The addition of microbes also affects the split tensile strength, this is shown by the bacterial specimens.. At the maximum point (40FAM) the strength of concrete with microbes increased by 10.5% when compared to 40FA.
4. The use of fly ash by 30%-40% can reduce the workability of the concrete due to fine particles of fly ash. This causes water was absorbed first by fly ash before reacting with cement. More superplasticizer was required with the increase of fly ash content because w/b was reduced. However, the application of microbes influence concrete workability at a lower fly ash content.
5. The effect of fly ash reduce the temperature of fresh concrete by 10% -12% because of reduction of cement content that lower the source of the heat.

Acknowledgments

The authors acknowledge the support received from PT Petrokimia Gresik for providing the fly ash. We also thank to PT Indocement Tunggul Prakarsa for providing the Portland Cement Composite.

References

- [1] Indonesian National Standard, SNI-03-2834-2000: *Procedure of Normal Concrete Mix Design*, Jakarta (in Indonesian).
- [2] Bahedh, M, A., dan Jaafar M, S., (2018), *Ultra High-Performance Concrete Utilizing Fly Ash as Cement Replacement under Autoclaving Technique*. CSCM, 202.
- [3] Rafeet, A., Vinai, R., Soutsos, M., Sha, W. (2017), *Guidelines for Mix Proportioning of Fly Ash/GGBS Based Alkali Activated Concretes*. Construction and Building Materials, 147, 130-142.
- [4] Marthinus, A, P., Sumajouw, M, D, J., Windah. R. S. (2015), *Effect of Addition of Fly Ash to Tensile Strength of Concrete*. Journal of Sipil Statik, 3, 11 (in Indonesian).
- [5] Wang, W., Lu, C., Li, Y., Li, Q. (2017), *An Investigation on Thermal Conductivity of Fly Ash Concrete After Elevated Temperature Exposure*. Construction and Building Materials, 148, 148-154.

- [6] Andalib, R., Majid, M, Z, A., Hussin, M, W., Ponraj, M., Keyvanfar, A., Mirza, J., Lee, H, S. (2016), *Optimum Concentration of Bacillus Megaterium for Strengthening Structural Concrete*. Construction and Building Materials, 118, 180-183.
- [7] Jagannathan, P., Narayanan, K, S, S., Arunachalam, K, D., Annamalai, S, K. (2018), *Studies on The Mechanical Properties of Bacterial Concrete with Two Bacterial Species*. Materials Today: Proceedings, 5, 8875-8879.
- [8] Xu, X., Liu, X., Li, Y., Ran, Y., Liu, Y., Zhang, Q., Li, Z., He, Y., Xu, J., Di. H. (2017), *High Temperatures Inhibited the Growth of Soil Bacteria and Archaea But Not That of Fungi and Altered Nitrous Oxide Production Mechanisms from Different Nitrogen Sources in An Acidic Soil*. Soil Biology & Biochemistry, 107, 168-179.
- [9] American Society for Testing and Materials C 494/C 494M – 19. (2019), *Standard Specification for Chemical Admixtures for Concrete*. ASTM International. United States.
- [10] Nursandah, A. dan Jannah, R, J. (2017), *The Influence of Bioconc Expired on the Concrete Compressive Strength*. Agregat, 2, 1 (in Indonesian).
- [11] Wulandari, K, D., Ekaputri, J, J., Triwulan, Fujiyama, C., Setiamarga, D, H, E. (2018), *Effects of Microbial Agents to The Properties of Fly Ash-Based Paste*. MATEC Web of Conferences, 195.
- [12] Velandia, D, F., Lynsdale, C, J., Provis, J, L., Ramirez, F. (2018), *Effect of Mix Design Inputs, Curing and Compressive Strength on the Durability of Na₂SO₄-Activated High Volume Fly Ash Concrete*. Cement and Concrete Composites, 3036.
- [13] Gopalakrishnan, R., Sounthararajan, V, M., Mohan, A., Tholkapiyan, M. (2019), *The Strength and Durability of Fly Ash and Quarry Dust Light Weight Foam Concrete*. Materials Today: Proceedings.
- [14] Chahal, N., Siddique, R., Rajor, A. (2012), *Influence of Bacteria on the Compressive Strength, Water Absorption and Rapid Chloride Permeability of Fly Ash Concrete*. Construction and Building Materials, 28, 351-356.
- [15] Asgharzadeh, M., Kafil, H. S., Fahmi, A., Yousefi, M., Aghazadeh, M., Hanifi, G. R., Pourostadi, M. (2016), *Optimizing The Use of Sporsarcina Pasteurii Bacteria for The Stiffening of Sand*. Asian Jr. of Microbial. Biotech. Enc. Sc, 18, 2.
- [16] Krishnapriyaa, S., Ventakesh, D, L., Babub, Arulraj G, P. (2015), *Isolation and Identification of Bacteria to Improve the Strength of Concrete*. Microbiological Research, 174, 48-55.
- [17] Kim, T., Davis, J, M., Ley, M, T., Kang, S., Amrollahi, P. (2018), *Fly ash Particle Characterization for Predicting Concrete Compressive Strength*. Construction and Building Materials, 165, 560-571.
- [18] Kavyateja, B, V., Jawahar, J, G., Sashidar, C. (2020), *Effectiveness of Alccofine and Fly Ash on Mechanical Properties of Ternary Blended Self Compacting Concrete*. Material Today: Proceedings.
- [19] Kadapure, S, A., Kulkarni, G, S., Prakash, K, B. (2016), *A Laboratory Investigation on The Production of Sustainable Bacteria-Blended Fly Ash Concrete*. Arab Journal Science Engineering.
- [20] Nguyen, T, B, T., Saengsoy, W., Tangtermsirikul, S. (2018), *Effect of Initial Moisture of Wet Fly Ash on the Workability and Compressive Strength of Mortar and Concrete*. Construction and Building Materials, 183, 408-416.
- [21] Siddique, R., Jameel, A., Singh, M., Barnat-Hunek, D., Kunal, Ait-Mokhtar, A., Belarbi, R., Rajor, A. (2017), *Effect of Bacteria on Strength, Permeation Characteristics and Micro-Structure of Silica Fume Concrete*. Construction and Building Materials, 142, 92-100.
- [22] Nagrockienė, D., Rutkauskas, A. (2018), *The Effect of Fly Ash Additive on the Resistance of Concrete to Alkali Silica Reaction*. Construction and Building Materials, 201, 599-609.
- [23] Benaicha, M., Alaoui, A, H., Jalbaud, O., Burtschell, Y. (2019), *Dosage Effect of Superplasticizer on Self-Compacting Concrete: Correlation between Rheology and Strength*. Journal of Materials Research and Technology, 8, 2063-2069.

- [24] Shahrin, R., Bobko, C, P. (2019), *Micropillar Compression Investigation of Size Effect on Microscale Strength and Failure Mechanism of Calcium-Silicate-Hydrates (C-S-H) in Cement Paste*. Cement and Concrete Research, 125, 105863.
- [25] Nain, N., Surabhi, R., V, Y, N., Krishnamurthy, V., Deepa, T., Tahrannum, S. (2019), *Enhancement in Strength Parameters of Concrete by Application of Bacillus Bacteria*. Construction and Building Materials, 202, 904-908.
- [26] Ekaputri, J, J., Ishida, T., Maekawa, K. (2010), *Autogeneous Shrinkage of Mortars Mode with Different Types of Slag Cement*. JCI Annual Conferences, Saitama, 7-9 July 2010, 1.
- [27] Matos, P, R, D., Junckes, R., Graeff, E., Prudêncio, L, R., Jr. (2020), *Effectiveness of Fly Ash in Reducing the Hydration Heat Release of Mass Concrete*. Journal of Building Engineering, 20, 101063.