Recent Trends in Civil Engineering and Built Environment Vol. 5 No. 1 (2024) 251-261

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Compressive Strength, Shrinkage Rate and Temperature Profile of Concrete Containing Varying Percentage of Fine Metakaolin

Mohd Amirul Hisham Kamal[1], Masni A. Majid [1]*, Mohd Hanif Ismail[1]

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Senior Lecturer, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia

DOI: https://doi.org/10.30880/rtcebe.2024.05.01.025
Received 23 June 2022; Accepted 01 January 2024; Available online 30 June 2024

Abstract: Supplementary cementitious materials (SCM) have shown to be a crucial component of concrete with exceptional strength and performance. One of the SCM materials, metakaolin (MK), is produced by calcining kaolinite. widely used as a pozzolanic ingredient in concrete to improve the strength and durability. The usage of ordinary Portland cement had result in increasing the negative affect due to its properties. This study is to investigate the concrete compressive strength by using fine metakaolin (FMK) in various ratios to partially replace cement in concrete mixture. For replacement fine metakaolin, different percentages were used which is 0%, 10%, and 15%. This mixture will be cast in two different types of moulds: a cube mould measuring 100mm x 100mm x 100mm and a prism mould measuring 100mm(W) x 100mm(H) x 300mm(L). The strength is measured after 7days, 28 days, and 56 days of curing. The concrete compressive test indicates that increasing in usage of FMK can increase the concrete compressive strength than ordinary concrete mixture. Optimum replacement of FMK for cement was 15% which increase the physical quality of concrete.

Keywords: Supplementary Cementitious Materials (SCM), Metakaolin (MK), Fine Metakaolin (FMK).

1. Introduction

Concrete technologists are experimenting with extra ingredients, such as mineral admixtures, to improve the compressive strength of concrete. Researchers are still experimenting with other materials that can be used in place of cement and aggregates, such as fly ash, metakaolin, silica fume, blast furnace slag, recycled aggregates, plastic aggregates, and many other supplementary materials. The selected option of alternative materials can help to reduce the depletion rate for the natural resources. Besides, it can help to improve the various properties of concrete like workability, durability, strength, resistance to cracks and permeability (John, 2013). Many current concrete mixes include admixtures that improve

*Corresponding author: masni@uthm.edu.my

the microstructure while also lowering the calcium hydroxide concentration by eating it through a pozzolanic reaction. The microstructure of cement composites is subsequently modified, which improves mechanical capabilities, durability, and service-life features. The selected supplementary material known as metakaolin. Metakaolin is a pozzolanic substance made from high-quality kaolin. When china clay, the mineral kaolin, is heated to a temperature between 6000C-8000C, it produces a product that is created for use rather than a by-product. Metakaolin is a porous, angular shaped, platy particle with a mean size that can range from 1 to 20 µm (Al-Akhras, 2006). The specific gravity of metakaolin can fall between 2.20 and 2.60 (Mardani-Aghabaglou ,2014).

Kaolin is used as a raw material in the production of metakaolin ($A_{l2}Si_2O_7$). At room temperature, metakaolin interacts with Ca $(OH)_2$ to generate CSH gel, and when combined with CH, it produces alumina-containing phases such as C_4AH_{13}, C_2ASH_8, and C_3AH_6 (Zhang and Malhotra, 1995).The usage of metakaolin has been studied in recent years in construction industry due to its properties that able to improve the level of compressive strength compared to concrete mixes commonly used in the construction industry. Besides, metakaolin or supplemental material does have positive and negative effects to environment and economic aspects meanwhile the use of metakaolin instead of cement does not substantially lessen abiotic depletion. In fact, 1.6 tonnes of limestone and clay are needed to make one tonne of Portland cement, but just 1.16 tonnes of kaolin are needed to manufacture one tonne of metakaolin. (Heath et al,2014). Furthermore, kaolin mining in the United Kingdom generates a lot of trash and may have an effect on the nearby aquatic environment. (Heath et al ,2014).

Table 1. Physical properties of metakaolin (Siddique & Klaus, 2009)

Property	**Value**
Specific gravity	2.6
Bulk density (g/cm^3)	0.3-0.4
Physical form	Powder
Colour	Off-white
GE brightness	79-82

Table 2. Chemical properties of metakaolin (Sangeetha & Rishisha, 2018)

Chemicals	Percentage (%)
SiO_2	52.0
Al_2O_3	46.0
Fe_2O_3	0.60 (MAX)
TiO_2	0.65 (MAX)
CaO	0.09 (MAX)
MgO	0.03 (MAX)
Na_2O	0.10 (MAX)
K_2O	0.03 (MAX)
LOSS ON IGNITION	1.00

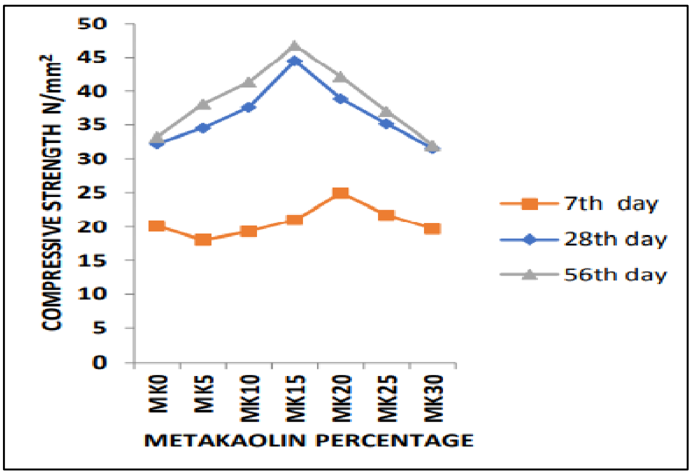


Figure 1. Variation of compressive strength with metakaolin content (Sangeetha & Rishisha, 2018)

The real goal of this research is to figure out the compressive strength and shrinkage rate on concrete mixed by several type of material such as Portland cement, aggregates, fine metakaolin, superplasticizer, and water based on various design ratio. The compressive strength of a material is determined by the ability of the material to resist failure in the form cracks and fissure. Meanwhile, the shrinking of concrete induced by moisture loss from drying concrete is known as shrinkage. Shrinkage-compensating concrete is used to minimize cracking and structural movement caused by drying shrinkage in concrete. The amount of drying shrinkage that occurs in concrete structures depends on the constituent materials, mixture proportions, curing, drying environment, and restraint based on American Concrete Institute (ACI). The investigated rheological properties, mechanical properties, and shrinkage of concrete are shown to be significantly affected by temperature changes (Mahdi Valipour and Kamal H. Khayat, 2020).

2. Materials and Methods

2.1 Materials

This study was consisted of several type of construction material such as Portland cement, fine aggregate which is sand, coarse aggregate which is crushed stone or gravel, water, supplementary cement material which is fine metakaolin, and chemical material that work as water reducer known as superplasticizer (SP) and the main variable materials in this study is fine metakaolin (FMK). Metakaolin made from purified kaolin, is not industrial waste product, can be recommended to be used along with Cement to derive certain enhanced properties for concrete in special situations. Metakaolin have more benefits compare to other pozzolanic materials such as fume, surkhi, and husk rice ash. Even as early as one day, high reactive metakaolin exhibits substantial pozzolanic reactivity and a decrease in Ca (OH)2. This study will be using a fine metakaolin type where the metakaolin particle are slightly different from ordinary metakaolin. Different in particle means different in grades of metakaolin. The quantity will be in varies percentage which is 0%, 10%, and 15% as cement replacement.

Figure 2. Bag of fine metakaolin

Figure 3. Metakaolin Powder

2.2 Mix proportion

The mixture also known as ratio of mixture are based on the concrete strength that required but in general guide a standard concrete mix would be 1:2:4 which means 1 indicates as cement, 2 as fine aggregate, and 4 as coarse aggregate. Meanwhile, this investigation will be using concrete grade of M50. The supplementary cement material will be added with varies percentage to observe the effect on the concrete. The SCMs material are fine metakaolin that will be added with 0%, 10%, and 15%. The percentage of fine metakaolin will be replaced with cement powder where the function was to reduce the usage of the Portland cement without effecting the concrete strength.

Table 3. Design mix using 1.5% SP for concrete cube

No	Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Water (kg)	FMK (kg)	SP (kg)	Total (kg)	No of Cube
1	19.80	26.712	37.224	5.34	-	0.297	89.379	6
2	17.82	26.712	37.224	5.34	1.98 (10%)	0.297	89.379	6
3	16.83	26.712	37.224	5.34	2.97 (15%)	0.297	89.379	6

Table 4. Design mix using 2% SP for concrete cube

No	Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Water (kg)	FMK (kg)	SP (kg)	Total (kg)	No of Cube
1	19.80	26.712	37.224	5.34	-	0.396	89.379	6
2	17.82	26.712	37.224	5.34	1.98 (10%)	0.396	89.379	6
3	16.83	26.712	37.224	5.34	2.97 (15%)	0.396	89.379	6

Table 5. Design mix using 1.5% SP for concrete prism

No	Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Water (kg)	FMK (kg)	SP (kg)	Total (kg)	No of Prism
1	19.80	26.712	37.224	5.34	-	0.297	89.379	3
2	17.82	26.712	37.224	5.34	1.98 (10%)	0.297	89.379	3
3	16.83	26.712	37.224	5.34	2.97 (15%)	0.297	89.379	3

Table 6. Design mix using 2% SP for concrete prism

No	Cement (kg)	Sand (kg)	Coarse aggregate (kg)	Water (kg)	FMK (kg)	SP (kg)	Total (kg)	No of Prism
1	19.80	26.712	37.224	5.34	-	0.396	89.379	3
2	17.82	26.712	37.224	5.34	1.98 (10%)	0.396	89.379	3
3	16.83	26.712	37.224	5.34	2.97 (15%)	0.396	89.379	3

2.3 Methods

Mixing concrete is simply defined as the "complete blending of the materials which are required for the production of a homogeneous concrete" (Young, 267). This can vary from hand to machine mixing, with machine mixing being the most common. Based on (Mahadev Desai, 2019), the steps in using mixer are:

i. Wet the inner drum of the mixer.

ii. Coarse aggregates are placed in the mixer first then followed by sand, cement and fine metakaolin.

iii. Mix the material in dry state in the mixer. Normally, take 1.5-3 minutes.

iv. After proper mixing in the dry state, gradually add the water with required quantity while the mixer under motion.

v. After adding of with water, mix the materials for 2 minutes.

vi. While machine under motion, add the last material which is superplasticizer into the mixture.

After done the mixture, the concrete will be casting or poured into the prepared mould. The mould for this study will be in 2 type which is concrete cube with size of 150mm x 150mm x 150mm, meanwhile second is concrete prism with size of 100mm x 100mm x 300mm. Both of this mould or size are chosen based on the testing that will be conducted after the concrete mixture is full dry or hardened.

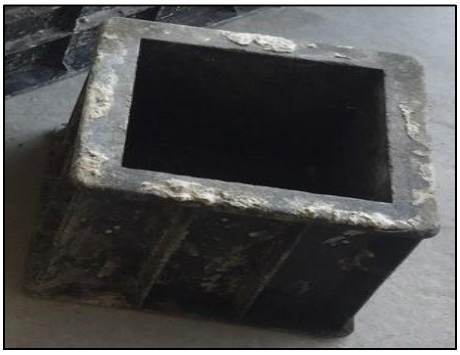


Figure 4. Cube mold

Figure 5. Prism mold

3. Results and Discussion

3.1 Slump Test

Table 7. Slump test

Concrete Mix	1.5% SP (mm)	2% SP (mm)
Control Mix	165	190
OPC+FMK10%	185	190
OPC+FMK15%	185	195

According to tables 7, the 2 % SP shows the greatest slump test value, which is a 7 percent rise above the 1.5 percent SP. This demonstrates that adding 2 percent SP to the concrete mixture material causes the slump of the concrete mixture to increase. The lower value of the slump test is 165mm for the control mix sample, meaning there was no additional cement material added, as contrasted to other samples that had FMK added in varying percentages to get a value of 185mm.

3.2 Slump Flow Test

Table 8. Slump Flow test

Concrete Mix	1.5% SP (mm)	2% SP (mm)
Control Mix	417	438
OPC+FMK10%	400	433
OPC+FMK15%	387	427

According to data tables 8, the use of chemical materials in the concrete mixture did have an impact on how workable it was. The slump flow test value increases with more chemical use, indicating that the concrete will be more workable. According to both sets of data, only concrete mixtures with 15% FMK have smaller slump flow radii than other mixtures, at 387 mm for 1.5% FMK, and 400 mm for 10% FMK, and 2% SP. This demonstrates how FMK, as opposed to regular concrete mixture, may impact the flow workability of concrete.

3.3 Compressive Strength Test

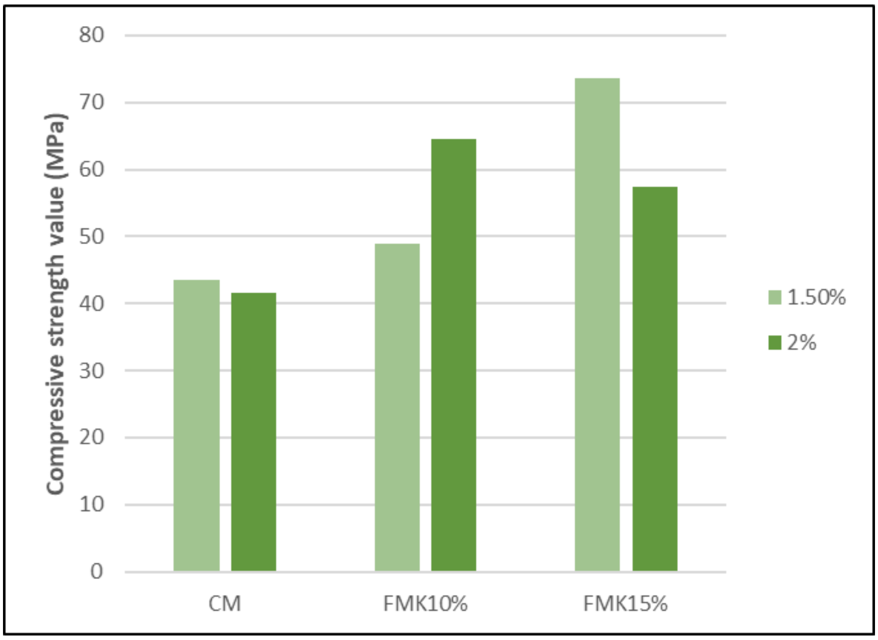


Figure 6. Relationship of concrete compressive strength with different percent of FMK and SP in 7 days

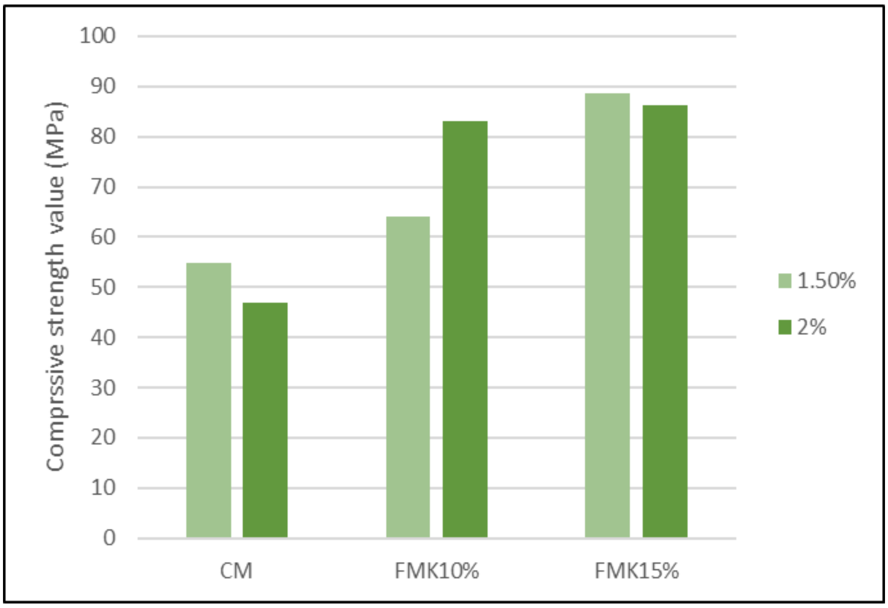
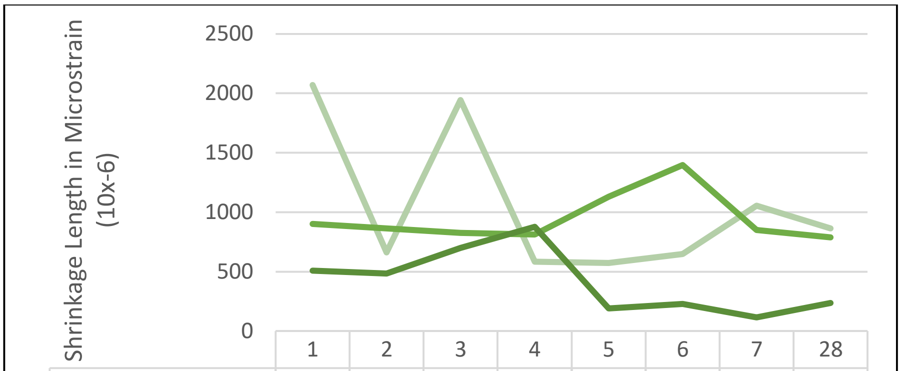


Figure 7. Relationship of concrete compressive strength with different percent of FMK and SP in 28 days

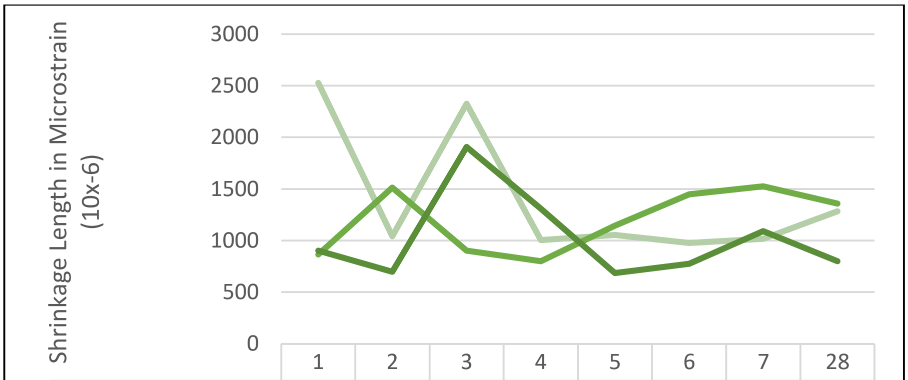
Based on figure 6 & 7, the graph demonstrates two distinct bar chart patterns for each control mix, FMK10% and FMK15%, where each bar represents 1.5% and 2% of SP. The graph demonstrates that concrete mixtures with 1.5 percent SP perform better than those with 2 percent SP, whereas concrete mixtures with FMK 10% and 2 percent SP exhibit the best compressive strength in comparison to the other two samples. Conversely, concrete made with 1.5 percent SP demonstrates that cement mixed with FMK has more compressive strength than regular concrete. The targeted concrete strength achieved on the 28 days.

3.4 Shrinkage Test



	1	2	3	4	5	6	7	28
cm sp1.5%	2070	660	1943	584	572	648	1054	864
fmk10% sp1.5%	902	864	826	813	1130	1397	851	787
fmk15% sp1.5%	508	483	699	876	191	229	114	237

Figure 8. Shrinkage concrete for 1.5% SP



	1	2	3	4	5	6	7	28
cm sp2.0%	2527	1041	2324	1003	1054	978	1016	1283
fmk10% sp 2.0%	864	1511	902	800	1143	1448	1524	1359
fmk15% sp2.0%	902	699	1905	1308	686	775	1092	800

Figure 9. Shrinkage concrete for 2% SP

Based on figure 8 and 9, control mixed or ordinary concrete mix having the higher shrinkage length in both using 1.5% SP and 2% SP. Meanwhile, for concrete mix with FMK 15% show consistency shrinkage length prove that the mixture able to control the moisture inside the concrete from day 1 to 28 days. This mean the ordinary concrete mix release more moisture and quick in adjusting its own temperature to the environment temperature compare to concrete mix with FMK. The result also affected by the surroundings temperature or weather conditions whether the ambient air is humid or hot dry.

3.4 Temperature Profile Test

Temperature profile test was conducted to observed how the concrete that has been mixed absorbs and releases heat to adapt to the temperature in the concrete environment. The temperature profile result of this study is shown in figure 10, 11, and 12 in forms of graph. This test was only run for 7 days from the day the concrete was poured into the mold. The temperature measured by hour start from casting till the day seventh. This test conducted in elected area with temperature similar to the ambient temperature.

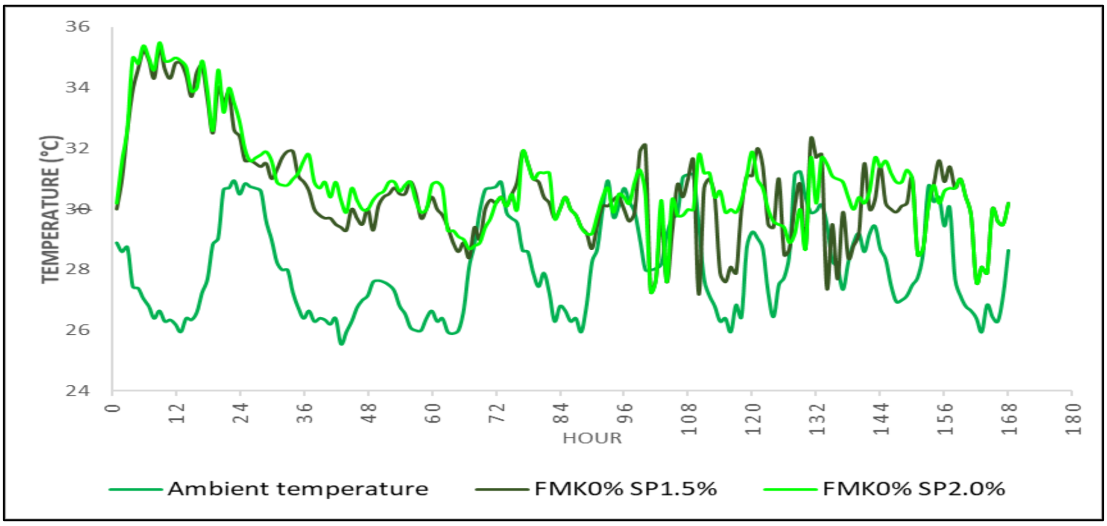


Figure 10. Temperature profile for concrete mixture in 7 Days

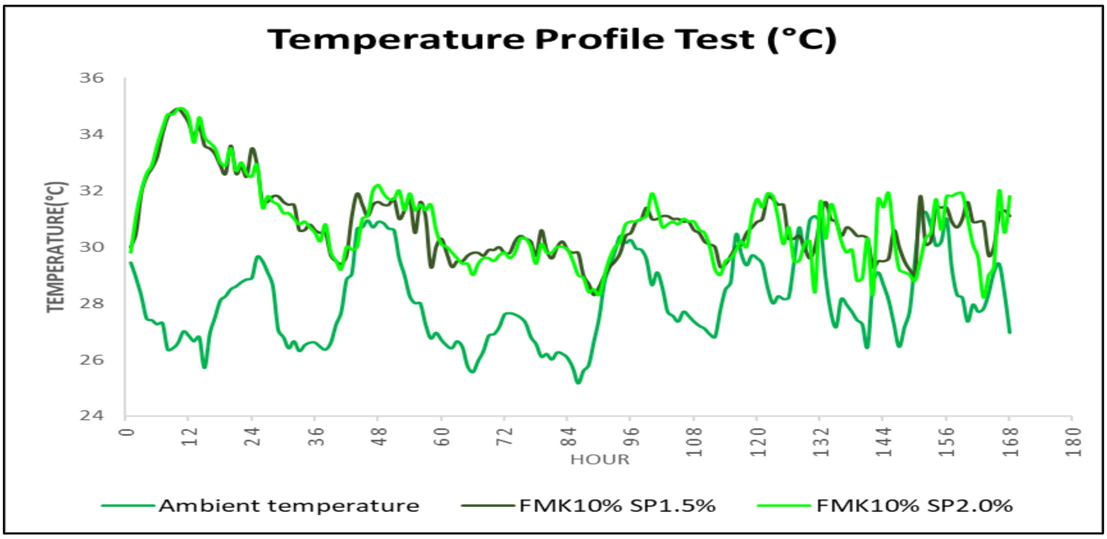


Figure 11. Temperature profile for concrete mix with FMK10% in 7 days

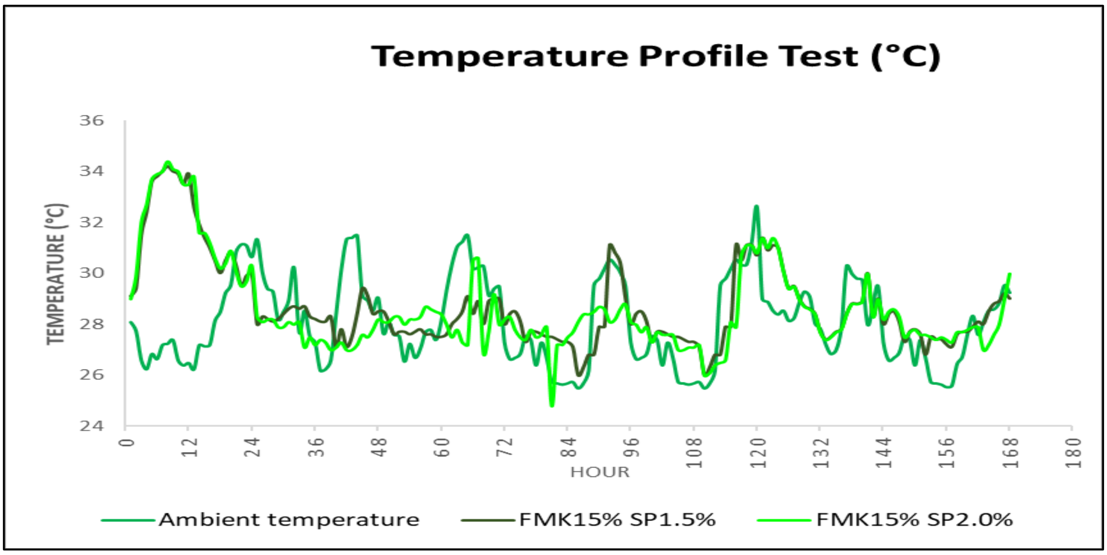


Figure 12. Temperature profile for concrete mix with FMK15% in 7 Days

Based on the graphs shown that all samples of concrete mix have higher temperature compared to ambient temperature or environment temperature. The graph shows that each concrete sample experiences a high temperature during the first day on 24 hours. This is due, because of the drying process faced by the concrete takes place on the first day. Ordinary concrete mix will have a higher temperature in the first day compared to FMK10% and FMK15%. This means, concrete mix with FMK can through the drying process in lower temperature compared to ordinary concrete mix. Obviously, all of the concrete mix were in range of maximum limits which is between 26.7°C and 35°C based on ASTM C 1064-86. The limit can be modified in accordance with project specifications.

4. Conclusion

Based on the above result and finding, the following conclusions can be drawn:

- Increasing of FMK 33% compared to ordinary concrete mixture can increase the concrete strength as much as 27.6% higher.
- The concrete mix with FMK can maintain its humidity when drying that also can reduce the possibility of concrete crack due to loss of water content. This can be proved when concrete mix with FMK 15% had differences 72% in length compared to ordinary concrete mixture.
- The temperature profile test did show an expected result where after the first 24 hour the temperature did drop to comply with the ambient temperature. The concrete temperature profile also can be determined in this study.

Acknowledgement

This research was made possible by funding from research provided by the Ministry of Higher Education, Malaysia. Thanks also to the faculty of civil engineering and built environment for their support and help in completing this study.

References

[1] Strength Properties of Metakaolin Admixed Concrete. International Journal of Scientific and Research Publications, 3(6), ISSN 2250-3153, June 2013.

[2] Durability of metakaolin concrete to sulfate attack, Cement and Concrete Research Volume 36, Issue 9, Pages 1727-1734, September 2006.

[3] Comparison of fly ash, silica fume and metakaolin from mechanical properties and durability performance of mortar mixtures view point, Construction and Building Materials, Volume 70, Pages 17-25, 15 November 2014.

[4] Characteristics of a thermally activated alumino-silicate pozzolanic material and its use in concrete, Cement and Concrete Research Volume 25, Issue 8, Pages 1713-1725, December 1995.

[5] Minimising the global warming potential of clay based geopolymers, Journal of Cleaner Production 78:75–83, DOI:10.1016/j.jclepro.2014.04.046, September 2014.

[6] Influence of Metakaolin on the Properties of Mortar and Concrete. Applied Clay Sci- ence, 43, 392-400. (Online). Available: http://dx.doi.org/10.1016/j.clay.2008.11.007

[7] Study of Concrete Strength Parameters Using Metakaolin as A Partial Replacement of Cement and M Sand as Fine Aggregate, International Journal of Engineering & Technology, 7 (2.33) (2018) 1123-1125International Journal of Engineering & TechnologyWebsite: www.sciencepubco.com/index.php/IJET

[8] American Concrete Institute (ACI), ACI 224R-01, 2012, https://www.concrete.org/Portals/0/Files/PDF/224R_01Ch3.pdf

[9] Design and performance of low shrinkage UHPC for thin bonded bridge deck overlay, Cement and Concrete Composites 118:103953, January 2021, DOI:10.1016/j.cemconcomp.2021.103953l.

[10] Effect of metakaolin on the properties of conventional and self compacting concrete, Advances in Concrete Construction, Vol. 5, No. 1, P31-48, (2017) DOI: https://doi.org/10.12989/acc.2017.5.1.31.

[11] Influence of Silicate Structure on the Low Temperature Synthesis of Belite Cement from Different Siliceous Raw Materials Concrete. New Jersey: Prentice-Hall, Inc., ISBN10: 0130646326, ISBN13: 9780130646323, 1981.

[12] Methods for Mixing of Concrete Their Procedure & Precautions, 17th September, 2019, (Online) Available: https://gharpedia.com/blog/methods-for-mixing-of-concrete-their-procedure-precautions.