© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJSCET

http://penerbit.uthm.edu.my/ojs/index.php/ijscet
ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Performance of Silica Gel as Moisture Removal from Mortar

Nickholas Anting Anak Guntor[1*], Alvin John Lim Meng Siang[2], Joewono Prasetijo[3]

[1]Jamilus Research Center, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, Johor, MALAYSIA.

[2]Research Centre for Soft Soil (RECESS), Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, Johor, MALAYSIA.

[3]Department of Transportation Engineering Technology (STSS), Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Panchor, Johor, MALAYSIA.

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2020.11.01.016
Received 24 February 2020; Accepted 30 March 2020; Available online 7 May 2020

Abstract: Silica gels are widely used as a desiccant to protect the product from moisture damage, which has capacity to absorb moisture from surrounding at level of 100% based on its own weight. Due to this performance, an innovative approach has been taken by applying the silica gel as moisture absorbance from mortar layer. The main objective of this research is to study the performance of silica gel as moisture absorption material that mainly to reduce the surface moisture of tested mortar samples. A series of procedures for experimental work has been designed purposely for this study. Three mortar samples with size of 300mm x 300mm x 50mm were prepared accordingly for each of sample with water-cement ratio of 0.40, 0.45 and 0.50. Initially, mortar samples were ponded with three liters of fresh water for period of 24-hours, and excess water were removed once completed. Then, data of surface moisture of mortar samples together with weight of silica gel was measured and collected simultaneously every 30 minutes for 6 hours. Experimental study found that S3, mortar with w/c of 0.5 had experienced the highest reduction of surface moisture rate of 0.047%/min due to the presence of silica gel. Silica gel, G2 that placed at the mortar with w/c of 0.45 has the highest rate of absorption of 0.119gram/min. When the number of usage increases, the performance of silica gel reduces. Lastly, a relationship is determined that as the surface moisture of tested mortar samples decreases, the weight of silica gel increases. As for the conclusion, selected silica gel showed a potential to be applied as moisture removal material for mortar, which then prevents the growth of mould or fungi.

Keywords: Silica gel; Moisture absorbance; Mortar surface moisture

**Corresponding author: nickholas@uthm.edu.my*

1. Introduction

The climate of Malaysia can categorize as a typical tropical climate. Malaysia is averaging 26.4°C annually, which 34°C is the average maximum daily temperature and 23°C is the average minimum temperature. About the relative humidity value, Malaysia is relatively averaging from 74% to 86%. This tropical climate condition is exactly suitable for the growth of fungi (Jamaludin, 2015; Wahab et. al., 2013). Penicillium chrysogenum and Aspergillus versicolor are the most superior fungal species that found in water damaged materials (Andersen et. al., 2011; Lappalainen, 2008). The minimum humidity that required by fungi to live is shown to be between RH 80 and 95% relying on other factors such as ambient temperature, exposure time, the type and surface conditions of building materials (Viitanen et. al., 2010).

A long-term high humidity of the mortar layer in the ground of the bathroom causes the growth of mold (US. Protection Agency, 2013). Fungi can be seen in black or green color. The medium for fungi to grow is a damp condition. Other than that, fungi also need food, oxygen and a temperature between 40 degrees and 100 degrees (Lstiburek et. al., 2002). Fungi can grow by extension of hyphae that are like tiny root hairs. Hence fungi can expand to cover many square feet of material. Fungi can produce spores that are like very small seeds, which can survive in conditions that are too sunny, hot, cold, dry or wet. Different species of fungi can actively live and tolerate temperature extremes, water stress, and significant changes in pH (Kubicek and Druzhinina, 2007). These spores will spread to a new location by the assistance of air currents (Lstiburek et. al., 2002). For example, scientists found that able to alter the moisture of the air around them, which they whip up winds that blow away their spores hence dispersing their spores (Daily Mail Reporter, 2013). While when there is too much mold, it can affect the health of a person. There are 300 of those known fungal diseases cause people to fall sick. Most of them are not dangerous but some are harmful to health (Garcia-Solache et. al., 2010; Hawksworth, 2001; Tedersoo et. al., 2015). Those fungi will produce allergens. Some allergic reactions will occur on a person who inhales or in contact with those allergens. Fungi cause allergic diseases such as allergic rhinitis, pharyngitis, laryngitis, airborne dermatitis, or allergic conjunctivitis (Zukiewicz-Sobczak, 2013). They will suffer from sneezing, red eyes, itchiness of the skin. But, if a person who suffers from asthma exposure to mold, the person will get an asthma attack or make your chronic asthma get worse. Factors influencing fungi growth in buildings are nutrient, temperature and humidity therefore, affecting indoor air quality. Furthermore, fungi can damage or destroy the building material such as the wood or gypsum board in a building (Kumar and Verma, 2010).

A bathroom is a place where has high water activity due to human activities such as shower and wash clothes. The floor structure of bathroom is made up of three main layers which are tiles, mortar and concrete layer. Water penetrates into the mortar layer through the gap within tiles by water mechanism (Arizzi and Cultrone, 2013). In the long term, the water-proofing layer within the mortar layer and concrete layer wear out and cause the penetration of water to underneath level. Hence, this increases the moisture content or relative humidity of underneath level building material. The building material becomes a medium for fungi growth because as long as a material building's average weight is over 0.75, the higher the risk of fungi growth (Nielsen et. al., 2004). In a research conducted, the growth of four fungal species from bathrooms was able to consume surfactants, soap and shampoo but not in high-temperature or dry conditions (Hamada and Abe, 2010).

Silica gel has great moisture adsorption properties at high humidity levels (Chua and Islam, 2015). Silica gel was first introduced in 1959 and used as buffering agent in museum to control the relative humidity for the exhibition case in museum (Weintraub, 2002). Due to their great pore surface area and good moisture adsorption capacity, silica gel normally will be used in industrial and residential applications. Hence, the purpose of this research is to prove the performance and the ability of silica gel as moisture absorbent to reduce the moisture content in the mortar layer. The chemical compound of the silica gel is silicon dioxide, with a chemical formula of SiO_2. When compared with other material such as activated alumina, silica gel able to absorb about 30% or higher of moisture content. Silica gel perform well with relative humidity falls between 50% to 80% (Satiya et. al., 2013; Ramzy, 2010).

The importance of this study is to produce a mitigation method of controlling growth of fungi for a building. This is because the growth of fungi not only adverse the health effect of person, but also causes deterioration of building material. By using this method, the fungi problem can be solved effectively. Rather than investing more on building material maintenance, this study provides a low cost to solve the fungi problem. The method that used to control the growth of fungi is by controlling the moisture content of the mortar.

In this research, silica gel is used as a moisture absorbance, to absorb the water vapor that, releases from the mortar layer. The moisture content reduces in the mortar level. Therefore, this study was conducted in order to investigate the potential and performance of silica gel as moisture absorbance from the mortar layer. As part of the experiment, the surface moisture content and weight of silica gel were taken. The performance of silica gel was concluded.

2. Literature Review

Fungi are a type of fungus, which has become a major environmental concern in homes. Fungi can produce allergic, infections and toxicity reactions in human. Fungi are different from plants, animals and bacteria. The cause of the growth of fungi is high moisture of mortar due to water leakage from the bathroom (Andersen et. al., 2011). A study shows that Penicillium chrysogenum and Cladosporium herbarum fungi greatly influences the useful properties of cement materials (Fiertak, 2015). The floor structure of the bathroom is mainly made of three layers; tile, mortar and concrete layer. The mortar is a mixture of sand, water and cement. The internal structure of mortar is porous (Zhao et. al., 2014). Therefore, the porosity structure of mortar allows the water from the bathroom to enter the mortar layer. Hence, the water will accumulate in the mortar. The humidity level of mortar increases. In a long time, the high humidity level of mortar promotes the growth of fungi on the building wall.

The mechanisms that involve moisture transport in mortar layer are vapor diffusion, capillary suction, and gravity flow (Brocken and Pel, 1995). Vapor diffusion allows water to move from regions of high vapor concentration to low concentration. This mechanism acts to move water vapor through the air, or porous materials such as mortar layer. However, capillary suction moves liquid moisture slowly and steadily through the porous structure of the mortar layer. This mechanism allows water to flow in narrow spaces without the assistance of gravity force. The liquid moisture transferred from a region of high liquid concentration to low concentration. The other mechanism that involved is gravity flow. Gravity flows allow large quantities of liquid water transferred. It often measured in liters per second, flow downwards through opening, cracks or air spaces when driven by gravity. But there is a requirement for gravity flow to occur, that is the opening must at least 0.04 inches or larger since capillary suction forces tend to overwhelm gravity forces in small pores (Straube, 2002).

The silica gel is recommended to be used to overcome the issue of the high moisture content of the mortar layer. Silica gel is also one of the most commonly used moisture sorption for physical adsorption. Other chemical reaction sorption is using calcium oxide (Qiu et. al., 2016). The vapor released from the mortar layer absorbed by the silica gel by putting silica gel inside a pipe system. Silica gel is a material that has a high absorbent property, which made synthetically from sodium silicate and sulfuric acid. The characteristic of silica gel is in beads form, transparent look, and porous form. Silica gel is designed in bead form because it has a higher mechanical strength than the granular form. Silica gel has an internal network of interconnecting microscopic pores and therefore they have a very large surface area. Silica gel beads contain millions of fine pores which able it to absorb up to 40 % of its weight. The mechanism to absorb water vapor from the mortar layer that involved in silica gel is known as adsorption process (Qiu et. al., 2016). During the adsorption process, the micro-capillaries of silica gel adsorbed to achieve vapor pressure equilibrium with the relative humidity of the surrounding air. The adsorption capacity of silica gel depends on a linear relationship between the equilibrium relative humidity and the percentage water uptake (Weintraub, 2002).

Adsorption is the process that removes water vapor from mortar, but, it is always confused with the term of absorption. Adsorption is a process that involved the adhesion of atoms, ion, or molecules from liquid, gas or dissolved solid to a surface of the adsorbent. Adsorption takes place when one substance is held inside another by physical bonds only. However, the absorption process differs with the adsorption process. Absorption is the process by which a fluid is dissolved by a liquid or a solid. In conclusion, absorption can be categories as the bulk phenomenon, whereas, the adsorption is categories as the surface phenomenon only. In the adsorption process, the molecules are held loosely on the surface of the adsorbent. And it can be easily removed from absorbent compared to absorption process (Atkins et. al., 2017).

Silica gel is manufactured by the process of condensation polymerisation of silicic acid. SiO groups will interlink during polymerisation process and this form colloidal particles which after that will be transform to viscous silica gel. However, certain siloxane groups which found at the surface of silica gel are then change into hydroxyl groups. These hydroxyl groups are then polarised and hydrogen bonds are form between them. A study emphasized that adsorption properties of silica gel is rely on the surface hydroxyl groups of silica gel. The adsorption of water molecules are executed by hydroxyl group through hydrogen bonding. Christy had done an experiment on the adsorption characteristics by using NIR spectroscopy. Imbalance in the concentrations of free silanol groups will decrease the adsorption properties of silica gel (Christy, 2012).

3. Methodology

3.1 Sample Preparation

Three sets of mortar sample with different water-cement (w/c) ratio were prepared in order to achieve different level of porosity. With increment of w/c ratio, it will increase the porosity of the mortar. The w/c ratio of the mortar samples are varied by 0.4, 0.45 and 0.5, which are labeled as S1, S2, and S3 respectively, as shown in Table 1.

Table 1 - Mix proportion for mortar samples

Sample	Water/Cement Ratio	Cement (kg)	Sand (kg)	Water (kg)
S1	0.40	2.90	6.53	1.16
S2	0.45	2.90	6.53	1.31
S3	0.50	2.90	6.53	1.45

In order to allow moisture to be released from mortar layer, a pipe sleeve with designated holes were placed on the middle of each sample as shown in Fig. 1. Once formwork is ready, then mixes of mortar samples as in Table 1, were poured and left to be hardened for 7 days under air curing. After that, all the formwork for each samples were removed. Three layer of waterproofing for each side, including bottom surface (except top surface) were applied in order that all liquid water and moisture only can released from mortar through designated pipe sleeve holes. Silica gel that been used in this study were supply by ZettaPac Sdn. Bhd., which claimed could absorb moisture at level of 35% based on its weight. Amount of silica gel is fixed at 150 grams for each tested sample.

Fig. 1 - Formwork with pipe sleeve

3.2 Experimental Work

Initially, tested samples were ponded with three (3) liters of water for period of 24 hours. Plastice type of Perspex was installed on each side of mortar sample to provide a space for filling 3 litres of water on the mortar. After 24 hours, excess water on mortar's surface that not infiltrated were removed and experimental work start after one hour later. Silica gel have been placed in empty bottle with holes that allow moisture to be absorbed during experiment. The bottle with silica gel were placed inside the pipe sleeve, with silica gel at same level with designated holes on pipe sleeve surface, as shown in Fig. 2.

Fig. 2 - Experimental setup

Laboratory used as a controlled environment. This is because surrounding humidity, temperature and wind velocity is more controllable compared to an opened space.

Surrounding humidity would affect the evaporation rate of mortar and the moisture level that absorbed by silica gel. High humidity of surrounding would cause the evaporation rate of mortar become slow. Furthermore, controlled environment is needed to ensure that silica gel is absorb the moisture from the mortar instead of surrounding air.

Surrounding temperature would affect the evaporation rate of mortar and the performance of silica gel. High surrounding temperature would cause the evaporation rate of mortar become high. The optimal air temperature for the silica gel to perform well is within the 25 to 35℃. Therefore, a controlled environment is needed to ensure that temperature is constant and not varying along the experiment.

Wind velocity of surrounding would affect the evaporation rate of mortar. High wind velocity surrounding would affect the evaporation rate become high and mortar will release more moisture from mortar.

4. Result and Discussion

4.1 Surface Moisture of Tested Samples

Data in Table 2 shows that at the beginning of experimental work, sample S3 has recorded the highest moisture content, which is 9.092% and followed by S2, and the lowest moisture content is achieved by sample S1 that recorded the value at 7.767%. This phenomenon can be explaining by the porosity of tested samples. Increasing the value of w/c ratio will increase the porosity of the mortar, which cause sample S3 absorbed more water into the mortar. This explain why sample S3 has the highest moisture content compared to sample S1 and S2.

Table 2 - Data of average surface moisture of tested samples

Time (min)	Surface Moisture Content (%)		
	S1	S2	S3
0m	7.80	8.92	9.09
30m	7.72	8.89	9.04
60m	7.66	8.87	9.00
90m	7.64	8.83	8.92
120m	7.61	8.79	8.84
150m	7.60	8.75	8.78
180m	7.58	8.73	8.75
210m	7.57	8.712	8.71
240m	7.56	8.71	8.67
270m	7.55	8.65	8.63
300m	7.51	8.65	8.58
330m	7.48	8.63	8.56
360m	7.47	8.61	8.55

Presence of silica gel has shown significant effects to the moisture release rate from mortar samples. As in Figure 3, surface moisture content of all tested samples decrease at almost constant rate over time. Figure 4 shows the comparison of decreasing rate of the moisture content of each of tested samples. S3 has the highest loss of surface moisture rate of 0.047%/min, followed by S2 has 0.026%/min and S1 which the least gradient of 0.022%/min. From the comparison of loss of surface moisture rate, it shows that mortar with high water cement ratio experienced the most decrement of surface moisture content. The porosity of mortar is increasing with the water cement ratio of mortar, when the porosity higher, high moisture transport occurred in the tested mortar samples. Hence, high porosity of mortar allows more moisture to flow out from the mortar absorbed by the silica gel.

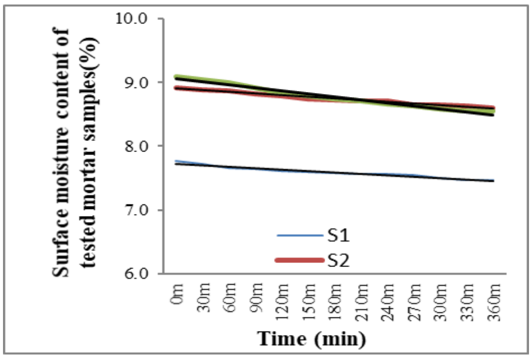

Fig. 3 - Graph of average surface moisture versus time

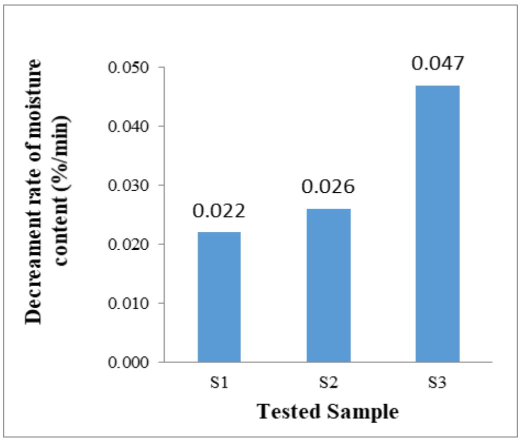

Fig. 4 - Decreasing rate of moisture content for tested samples

4.2 Effect of Silica Gel towards Mortar Samples with varies Water/Cement Ratio

The weight of silica gel was recorded every 30 minutes for total period of six hours, as shown in Table 3. Three tested silica gel showed an increasing trend line from the graph in Fig. 4, which means that thus tested silica gel experienced in absorbing of moisture from mortar then resulted an increment of its weight. From the data in Table 3, at the end of the experiment, silica gel sample G2 has achieved the highest weight of 151.570 gram, followed by G3, 151.470 gram and the least one was G1, 151.300 gram.

Table 3 - Collected weight of silica gel

Time (min)	Weight of silica gel (gram)		
	G1	G2	G3
0	150.00	150.00	150.00
30	150.23	150.30	150.33
60	150.30	150.43	150.40
90	150.43	150.57	150.53
120	150.50	150.67	150.63
150	150.60	150.80	150.77
180	150.73	150.90	150.87
210	150.87	151.00	150.93
240	150.90	151.10	151.07
270	151.00	151.23	151.13
300	151.13	151.33	151.27
330	151.23	151.43	151.37
360	151.30	151.57	151.47

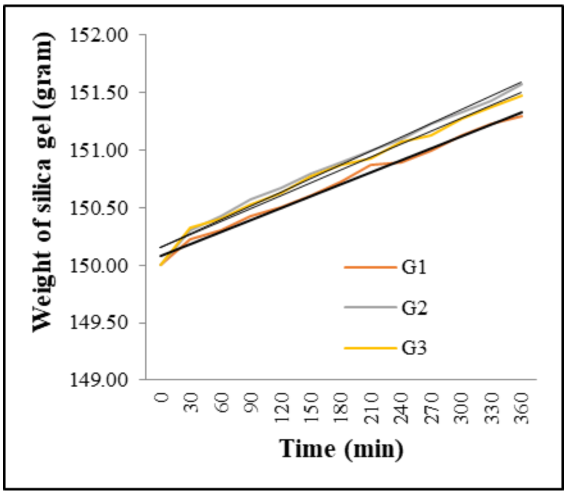

Fig. 4 - Graph of weight of silica gel versus time

The rate of absorption of silica gel compared as shown in Fig. 5. From the comparison, G2 has the highest rate of absorption of 0.119gram/min followed by G3 and G1, which are 0.112gram/min and 0.104gram/min respectively. Overall, silica gel able to absorb more moisture at the mortar with higher w/c ratio due to its high porosity, which then cause moisture easily to be released from the mortar sample.

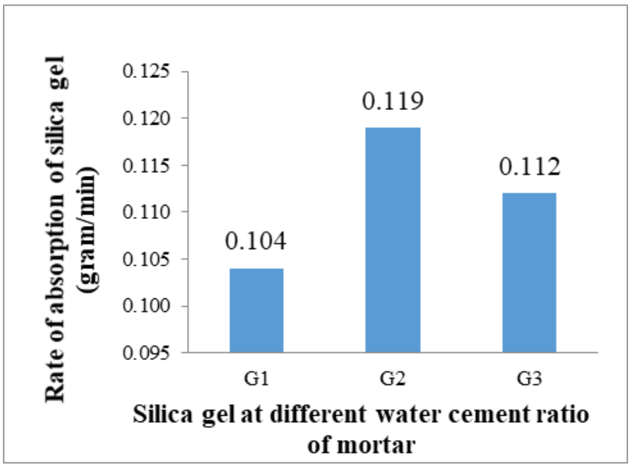

Fig. 5 - Rate of absorption of tested silica gel

Data collection were continuing by using used silica gel, which were placed at oven at 70 °C to be rejuvenated again after its first usage. The rejuvenated silica gel was then used again at the second and third test. Data that obtained for each of silica gel samples were represented in trend line as shown in Fig. 6. The graph shown that all tested silica gel experiencing an increasing trend line for both second and third data collecting work. Best fitted regression line has been plotted in Fig. 6 and summary of calculated gradient that indicated rate of absorption of tested silica gel have been shown in Fig. 7.

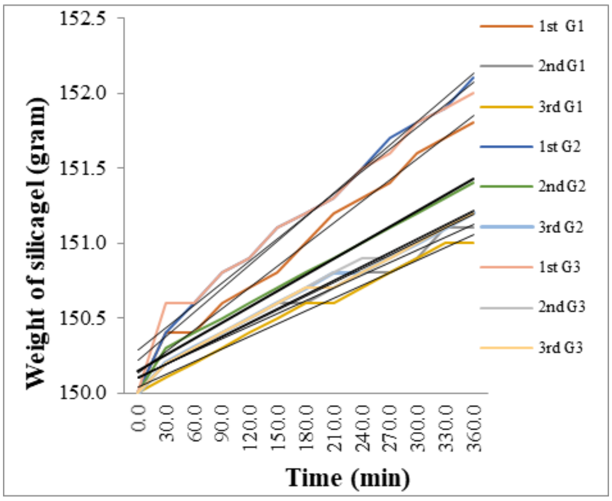

Fig. 6 - Weight of tested silica gel for first, second and third test

From Fig. 7, in the first absorption test, G1 has an absorption rate of 0.143 gram/min, G2 has an absorption rate of 0.159 gram/min, and G3 has an absorption rate of 0.149 gram/min. However, when the silica gel was placed in the oven with 70°C to be rejuvenated again and reused again at the second test, the absorption rate of silica gel has drastically dropped. In the second absorption test, G1 experienced drop of absorption rate from 0.143 gram/min to 0.087 gram/min, G2 from 0.159 gram/min to 0.107 gram/min, G3 from 0.149 gram/min to 0.093 gram/min. After the second test, the silica gel was then again rejuvenated and reused again at the third moisture absorption test. However, in the third moisture absorption test, the absorption rate of silica gel was just slightly decreased. G1 experienced drop of absorption rate from 0.087 gram/min to 0.085 gram/min, G2 from 0.107 gram/min to 0.092 gram/min, G3 from 0.093 gram/min to 0.092 gram/min. This situation proved that the performance of silica gel decreases when the usage number increases.

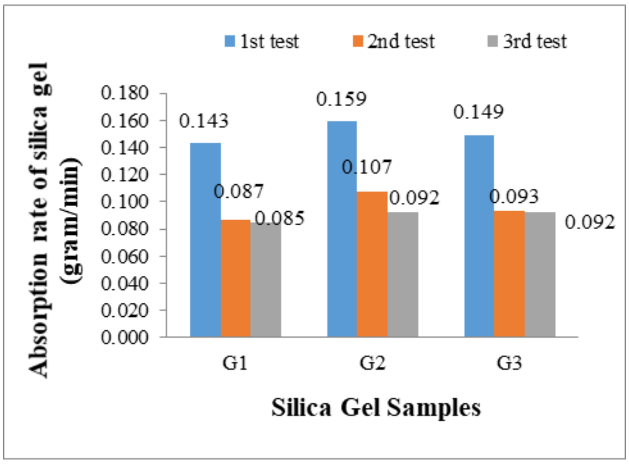

Fig. 7 - Absorption rate of silica gel for each mortar sample

4.3 Relationship between average surface moisture content of mortar and weight of silica gel

Fig. 8 shows the relationship between surface moisture of mortar sample and weight of silica gel that been assigned accordingly. From the plotted graph, it shows that surface moisture of mortar samples decreases proportionally with increasing weight of silica gel. This clearly indicate that presence of silica gel significantly absorbed moisture from mortar layer. Porosity is one of another parameter that contribute to the release rate of moisture to be absorbed by silica gel. Highest decreasing rate of surface moisture is recorded by sample G3, which is at rate of -0.42%/gram, significantly higher compared to both sample G1 and G2 that recorded decreasing rate at -0.25%/gram and -0.22 respectively. As it is known, sample G3 has the highest porosity, which definitely allow the moisture to be release easily from the mortar sample compared to others. Presence of silica gel significantly enhances moisture absorption from the mortar sample.

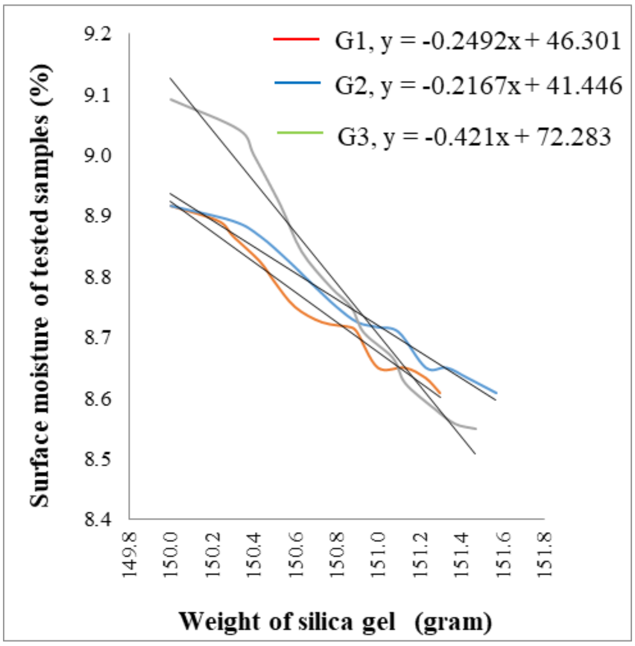

Fig. 8 - Relationship between average surface moisture content of mortar with weight of silica gel

5. Conclusion and Recommendation

In conclusion, the mortar sample with w/c of 0.5, which has the highest porosity had experienced the most decrement of surface moisture with the presence of silica gel. Porosity is one of important parameters that significantly affect the result of moisture removal performance of the silica gel.

For the purpose to extend and complement of the results, some recommendations for further studies are suggested. In this study, the silica gel is placed in a bottle with holes. However due to workmanship challenges, the size of all holes on bottle is not in even size and it would affect the result of absorption test. Hence a fixed apparatus is recommended to be used. Other than that, the evenness of mortar surface should be considered because even surface can make sure the surface of mortar is contact well with moisture meter during taking of moisture reading. Furthermore, the mortar sample should be placed in polystyrene box for achieving the controlled environment. It can prevent the moisture on mortar surface transport to surrounding environment. In addition, the silica gel should have to rejuvenated at the 90°C for 12 hours so that the moisture inside silica gel can be fully removed.

Acknowledgement

Special thanks for Universiti Tun Hussein Onn for their financial contribution in term of research grant, Product Development Grant through ICC UTHM under vote number B064.

References

Andersen, B., Frisvad, J. C., Sondergaard, I., Rasmussen, I. S. and Larsen, L. S. (2011). Associations between Fungal Species and Water-Damaged Building Materials. Applied and Environmental Microbiology, 77 (12), 4180-4188.

Arizzi, A. & Cultrone, G. (2013). The influence of aggregate texture, morphology and grading on the carbonation of non-hydraulic (aerial) lime-based mortars. Quarterly Journal of Engineering Geology and Hydrogeology, 46, 507-502.

Atkins, P., Paula, D. P., and Keeler, J. (2017). Atkins' Physical Chemistry (11th Ed.) Oxford: Oxford University Press.

Brocken, H. J. P. and Pel, L. (1995). Moisture transport over the brick-mortar interface. International Symposium on moisture problems in building walls, Porto, Portugal.

Christy.A.A. (2012). Effect of Heat on the Adsorption Properties of Silica Gel. International Journal of Engineering and Technology, 4 (4), 484-488.

Chua, K. J and Islam, M. R. (2015). On the experimental study of composite desiccants for energy efficient air dehumidification. IIUM Engineering Journal, 16 (2), 1- 11.

Daily Mail Reporter. (2013). Mushrooms make their own WEATHER: Fungi alter nearby air humidity to create 'wnds' that spread their spores far and wide. Retrieved on September 19, 2018 from https://www.dailymail.co.uk/sciencetech/article-2513292/Mushrooms-make-WEATHER-Fungi-alter-nearby-air humidity-create-winds-spread-spores-far-wide.html.

Fiertak, M., Stanaszek-Tomal, E., Kozak, A. (2015). The growth of fungi and their effect on the behavior of cement-polymer composites. Advances in Cement Research, 27 (6), 340-351.

Garcia-Solache, M.A., Casadevall, A. (2010). Global warming will bring new fungal diseases for mammals. Journal of mBio, 1 (1), 1 - 3.

Hamada, N. and Abe, N. (2010). Growth characteristics of four fungal species in bathrooms. Biocontrol Science, 15 (3), 111 - 115.

Hawksworth, D.L. (2001). The magnitude of fungal diversity: the 1.5million species estimate revisited. Mycological Research, 105 (12), 1422-1432.

Jamaludin, N., Mohammed, N. I., Khamidi, M. F. and Wahab, S. N. A. (2015). Thermal Comfort of Residential Building in Malaysia at Different Micro-Climates. Procedia-Social and Behavioral Sciences, 170, 613-623.

Kubicek, C. P. and Druzhinina, I. S. (2007). Fungi in extreme environments: Environmental and microbial relationships. Berlin: Springer.

Kumar, M. & Verma, R.K. (2010). Fungi diversity, their effects on building materials, occupants and control - a brief review. Journal of Scientific & Industrial Research, 69, 657-661.

Lappalainen, S., Salonen, H., Lindroos, O. Harju, R. Reijula, K. (2008). Fungal species in mold-damaged and non-damaged office buildings in southern Finland. Scandinavian Journal of Work, Environmental and Health, 4, 18-20.

Lstiburek, J., Brennan, T., and Yost, N. (2002). What You Need to Know About Mold. Building Science Corporation, Research Report - 0208.

Nielsen, K. F., Holm, G., Uttrup, L. P. and Nielsen, P. A. (2004). Mould growth on building materials under low water activities. Influence of humidity and temperature on fungal growth and secondary metabolism. International Biodeterioration & Biodegradation, 54 (4), 325 - 336.

Ramzy, A. K., Hamed, A. M., Awad, M. M. and Bekheit, M. M. (2010). Theoretical investigation on the cyclic operation of radial flow desiccant bed dehumidifier. Journal of Engineering and Technology Research, 2 (6), 96-110.

Qiu, Y., Chen. Y., Zhang, G., Yu, L. and Mantri, R. V. (2016). Developing Solid Oral Dosage Forms (2nd Edition): Pharmaceutical Theory and Practice. Academic Press, United States of America.

Satiya, S., Mann, S.S., and Aggarwal, A. (2013). Performance evaluation and regeneration of silica gel by using solar energy with Parabolic dish collector. International Journal of Latest Trends in Engineering and Technology, 2 (2), 186-196.

Straube, J. F. (2002). Moisture in buildings. ASHRAE Journal, 15-19.

Tedersoo, L., Bahram, M., Polme, S., Koljalg, U., Yorou, N.S., Wijesundra, R., et. al. (2015). Global diversity and geography of soil fungi. Science Magazine, 346 (6213).

United States Environmental Protection Agency. (2013). Moisture Control Guidance for Building Design, Construction and Maintenance. Retrieved on September 19, 2018 from www.epa.gov/iaq/moisture.

Viitanen, H., Vinha, J., Salminen, K., Ojanen, T. and Peuhkuri, R. H. (2010). Moisture and bio-deterioration risk of building materials and structures. International Association of Building Physics, 33(3), 201-224.

Wahab, A. N. S., Khamidi, M. F. and Ismail, M. R. (2013). An investigation of mould growth in tropical climate building. Business Engineering and Industrial Applications Colloquium, 316-321.

Weintraub. S. (2002). Demystifying silica gel. Objects Specialty Group Postprints, 9, 169-194.

Zhao, H., Xiao, Q., Huang, D. and Zhang, S. (2014). Influence of pore structure on compressive strength of cement mortar. The Scientific World Journal, 247058.

Zukiewicz-Sobczak, W.A. (2013). The role of fungi in allergic diseases. Postepy Dernatol Alergol, 30 (1), 42 - 45.