PERFORMANCE OF CONCRETE CONTAINING MICROWAVED SEWAGE SLUDGE ASH AS ADDITIONAL MATERIAL

MUHAMMAD AIZAT BIN AZED

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

____

(Supervisor's Signature)

Full Name : DR DOH SHU ING

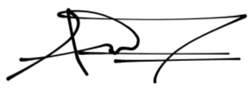
Position : SENIOR LECTURER

Date : 6 SEPTEMBER 2021

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.



____

(Student's Signature)

Full Name : MUHAMMAD AIZAT BIN AZED

ID Number : MAC16008

Date : 6 SEPTEMBER 2021

PERFORMANCE OF CONCRETE CONTAINING MICROWAVED SEWAGE SLUDGE ASH AS ADDITIONAL MATERIAL

MUHAMMAD AIZAT BIN AZED

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

College of Engineering
UNIVERSITI MALAYSIA PAHANG

SEPTEMBER 2021

ACKNOWLEDGEMENTS

First and foremost, I'd like to take this opportunity to express my gratitude to Universiti Malaysia Pahang (UMP) for the good facilities and equipment in the laboratory to finish my research. I am grateful UMP can provide us a comfortable working environment and refined equipment.

I'd like to express my heartfelt gratitude to Dr. Doh Shu Ing, my beloved research supervisor, for his unwavering support during my studies. Without his guidance, motivation, support and enthusiasm, I would be unable to complete my research with successful results. His courage enables me to strive better in this research. I really appreciate and will remember his good deeds to me emotionally, mentally and financially for my better future, forever.

A special thanks to my father, Azed Bin Hj Mohd Sidek, my mother, Julia Bt Bahari and all of my siblings for their love and encouragement all the way to complete my master studies in UMP. Thank you for never giving up on me.

Finally, I am also grateful as Allah sent me many supportive, loving friends and family during my ups and downs journey, for all the happiness and tears we had. Especially, Suhaily Suhaimi, Mohd Mukhris Awang; Encik Mohamad Najib Mohd Nor, Encik Wan Nazrul Helmy, Encik Nasrul Salim Pakheri and family, Muhammad Asyraf Abdullah, Muhammad Nur Arif Asri, Mohamad Fathin Mohd Zakiyuddin, my lab mates, all InSmartive and my Residential College 4 and Residential College 5 families. Their friendships enlighten my life. Last but not least thank you also to all of those people who have been involved in bring cheerful and happiness to me during my studies wherever you are. I love you guys so much.

ABSTRAK

Jumlah penduduk bandar di Malaysia merupakan 72.8% daripada jumlah keseluruhan penduduknya, dan angka ini dijangka bertambah setiap tahun. Malaysia sendiri menghasilkan 3.2 juta m^3 enap cemar kumbahan setiap tahun. Kebiasaannya, semua sisa buangan ini dibuang melalui kaedah kambus tanah. Ini merupakan ancaman serius bagi alam sekitar kerana kandungan toksik yang tinggi pada enap cemar kumbahan jika dibuang tanpa kawalan yang ketat. Selain itu, proses konvensional pengeluaran simen di industri dan penghasilan abu enap cemar kumbahan sebelum ini menggunakan banyak tenaga dengan menggunakan proses insinerasi dengan suhu yang sangat tinggi. Oleh itu, kaedah pemanasan gelombang mikro adalah alternatif yang digunakan dalam penyelidikan ini untuk mengurangkan penggunaan tenaga dan masa yang digunakan untuk memanaskan abu kumbahan dalam penghasilan bahan tambah pada konkrit. Penyelidikan ini dilakukan untuk mengkaji prestasi suhu optimum membakar bahan enap cemar kumbahan menggunakan kaedah gelombang mikro dalam menghasilkan Abu Kumbahan Gelombang Mikro (MSSA), seterusnya mengkaji kesan penggunaan peratusan MSSA yang berbeza (0%, 5%, 10%, 15% dan 20%) melalui kaedah pengawetan yang berbeza (pengawetan udara dan pengawetan air) serta menguji sifat mekanikal dan juga sifat ketahanannya terhadap keadaan persekitaran yang agresif. Ciri Abu Kumbahan Gelombang Mikro (MSSA) ini diuji dengan ujian Pendarflour Sinar-X (XRF), Belauan Sinar-X (XRD) dan Mikroskop Elektron Pengimbas (SEM). Sifat mekanikal konkrit MSSA diperiksa dengan ujian kekuatan mampatan, kekuatan lenturan dan modulus keanjalan setelah 180 hari pengawetan. Sementara itu, sifat ketahanan konkrit MSSA terhadap keadaan persekitaran agresif dikenal pasti dengan menggunakan ujian serangan asid dan rintangan sulfat. Ujian penyerapan air juga dilakukan untuk menentukan prestasi rendaman konkrit MSSA. Berdasarkan hasil ujian, kaedah pembakaran dengan Mod Suhu Tinggi menunjukkan perkembangan yang baik berbanding Mod Suhu Sederhana dan Sederhana Tinggi. Ini adalah disebabkan oleh kehadiran Silikon Dioksida yang tinggi sebagai elemen penting dalam penghasilan reaksi pozolona pada perkembangan kekuatan konkrit. Sampel yang diuji dengan pengawetan air dan mengandungi 5% MSSA (W5) mempunyai hasil yang terbaik dibandingkan dengan spesimen lain dari sudut sifat mekanikal dan prestasinya terhadap persekitaran agresif. Sifat mekanik kandungan MSSA 5% (W5) dalam konkrit menunjukkan sampel yang paling optimum kerana kepadatan tindak balas pozzolanik dan kesan pengisinya. Prestasi mekanikal terendah adalah MSSA 20% pada kedua-dua jenis pengawetan. Kesan pengawetan dengan hasil yang lebih baik adalah pengawetan air, kerana mendapat nilai kekuatan tertinggi dalam uji mampatan, ujian lenturan dan ujian modulus keanjalan. Pengawetan air dengan MSSA 5% (W5) juga menunjukkan ketahanan daya tahan terbaik terhadap serangan sulfat dan asid. Sebagai kesimpulan, berdasarkan hasilnya, MSSA menunjukkan kesan positif terhadap penggunaannya sebagai bahan tambahan pada campuran simen untuk meningkatkan kualiti konkrit. Oleh itu, ini akan mengurangkan pembuangan sisa kumbahan di tempat pembuangan sampah dan meningkatkan prestasi kualiti konkrit.

ABSTRACT

Urban population of Malaysia is stated as 72.8% of its total population, and growing every year. Malaysia itself produces 3.2 million m^3 of sewage sludge annually. Normally all of this waste is disposed by using landfill method. This is a serious threat to environment due to the high toxic content of sewage sludge if disposed it without strict control. Furthermore, usual production of cement and sewage sludge ash consumes a lot of energy by using incineration process with a very high temperature. Thus microwave heating method seen as an alternatives use in this research to reduce the consumption of energy and time used to heat the sewage sludge ash. The aim of this study was to identify the optimum microwave temperature in producing Microwave Sewage Sludge Ash (MSSA), to determine the performances of varied percentage (0%, 5%, 10%, 15% and 20%) of the MSSA concrete with different curing regime (air and water curing). Furthermore, to analyse its mechanical properties and performance towards aggressive environment. The optimum temperature of burning of MSSA was tested by X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD) and Scanning Electron Microscope (SEM) test. The mechanical properties of MSSA concrete was examined by compressive strength test, flexural Strength and modulus of elasticity after 180 days of curing. While, the performances of the MSSA concrete towards aggressive environment were identified by using Acid Attack test and Sulphate Resistance test. Water absorption test were also conducted to determine the percentage of water absorbed by MSSA concrete. Based on the result, High Temperature Mode was found the best in result compared to Medium and Medium High Temperature Mode. This is due to the high availability of Silicon Dioxide as the important pozzolanic element in the concrete strength development. Water curing with 5% of MSSA (W5) shown the best in results compared to other specimens in term of mechanical properties and its performance towards aggressive environment. The mechanical properties of 5% MSSA content in concrete shows the most optimum samples due to the densification of pozzolanic reaction and filler effect of MSSA. The lowest mechanical performance was sample with 20% content of MSSA for both curing method. The curing effect with better result was water curing, as it shown highest value of strength in all mechanical performance test. Water curing with 5% MSSA (W5) also shows best in durability resistance towards sulphate and acid attack. As conclusion, based on the results, it is shown the positive impact on using the MSSA as additional material to the cement mixture as it improves the quality of the concrete. Thus, this initiative can help in reduce the disposal activity of sewage sludge waste on dumping site and improves the quality performances of the concrete.

TABLE OF CONTENT

REFERENCES

A.M., Neville. (2011). Concrete Technology. In *Pearson Education Limited*. https://doi.org/10.1201/9780429275111

Abdel-Shafy, H. I., & Mansour, M. S. M. (2018). Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum*, *27*(4), 1275–1290. https://doi.org/10.1016/j.ejpe.2018.07.003

ACI Committee 318. (2008). "Building Code Requirement for Structural Concrete and Commentary"(ACi 318-08). *American Concrete Institute*, Farmington Hills, 473 pp

Aguiar, L. W., Otto, G. P., Kupfer, V. L., Fávaro, S. L., Silva, C. T. P., Moisés, M. P., de Almeida, L., Guilherme, M. R., Radovanovic, E., Girotto, E. M., & Rinaldi, A. W. (2020). Simple, fast, and low-cost synthesis of MIL-100 and MIL-88B in a modified domestic microwave oven. *Materials Letters*, *276*. https://doi.org/10.1016/j.matlet.2020.128127

Ajay, A., Ramaswamy, K. P., & Thomas, A. V. (2020). A critical review on the durability of geopolymer composites in acidic environment. *IOP Conference Series: Earth and Environmental Science*, 1–11. https://doi.org/10.1088/1755-1315/491/1/012044

Akçaoğlu, T., Çubukçuoğlu, B., & Tarassoly, A. R. (2020). Effects of glass powder as a supplementary cementitious material on the performance of high strength mortars. *Journal of Testing and Evaluation*, *48*(5). https://doi.org/10.1520/JTE20180140

Al-Obaidi, A. R., Al-Anbari, R. H., & Hassan, M. S. (2021). Sewage sludge reuse in concrete industry: A review. *IOP Conference Series: Earth and Environmental Science*, *779*(1). https://doi.org/10.1088/1755-1315/779/1/012010

Alexander, M., & Beushausen, H. (2019). Durability, service life prediction, and modelling for reinforced concrete structures – review and critique. *Cement and Concrete Research*, *122*(May), 17–29. https://doi.org/10.1016/j.cemconres.2019.04.018

Allahverdi, A., Akhondi, M., & Mahinroosta, M. (2018). A composite cement of high magnesium sulphate resistance. *Materiales de Construccion*, *68*(330), 1–11. https://doi.org/10.3989/mc.2018.11316

Antonkiewicz, J., Popławska, A., Kołodziej, B., Ciarkowska, K., Gambuś, F., Bryk, M., & Babula, J. (2020). Application of ash and municipal sewage sludge as macronutrient sources in sustainable plant biomass production. *Journal of Environmental Management*, *264*(November 2019). https://doi.org/10.1016/j.jenvman.2020.110450

Arel, H. (2016). Effects of foreign substances in cement mortar mixing water. *Advances in Cement Research*, *28*(3), 1–11.

Ball, H. (2018). What is Cement Vs Concrete?: Misinformation and Misunderstanding about the Two Definitions. *SAGE Journals*, *67*(1), 34–38.

Bennamoun, L., Chen, Z., & Afzal, M. T. (2016). Microwave drying of wastewater sludge: Experimental and modeling study. *Drying Technology*, *34*(2), 235–243. https://doi.org/10.1080/07373937.2015.1040885

BS EN 410:2000. (2000) Test Sieve: Technical Requirement and Testing, *British Standard Instituition.*

BS EN 12350-2:2000. (2000) Testing Fresh Concrete - Part 2. Slump Test

BS EN 118:122: Method of Determination of Water Absorption, *British Standard Instituition.*

Central Intelligence Agency. (2020). *Central Intelligents Agency: Malaysia*. https://www.cia.gov/library/publications/the-world-factbook/geos/my.html

Chakraborty, S., Jo, B. W., Jo, J. H., & Baloch, Z. (2017). Effectiveness of sewage sludge ash combined with waste pozzolanic minerals in developing sustainable construction material: An alternative approach for waste management. *Journal of Cleaner Production*, *153*, 253–263. https://doi.org/10.1016/j.jclepro.2017.03.059

Chang, Z., Long, G., Zhou, J. L., & Ma, C. (2020). Valorization of sewage sludge in the fabrication of construction and building materials: A review. *Resources, Conservation and Recycling*, *154*(November 2019), 104606. https://doi.org/10.1016/j.resconrec.2019.104606

Chen, G., Wang, X., Li, J., Yan, B., Wang, Y., Wu, X., Velichkova, R., Cheng, Z., & Ma, W. (2019). Environmental, energy, and economic analysis of integrated treatment of municipal solid waste and sewage sludge: A case study in China. *Science of the Total Environment*, *647*, 1433–1443. https://doi.org/10.1016/j.scitotenv.2018.08.104

Chen, L., Liao, Y., & Ma, X. (2019). Heavy metals volatilization characteristics and risk evaluation of co-combusted municipal solid wastes and sewage sludge without and with calcium-based sorbents. *Ecotoxicology and Environmental Safety*, *182*(May), 109370. https://doi.org/10.1016/j.ecoenv.2019.109370

Chen, L., Liao, Y., Ma, X., & Niu, Y. (2020). Effect of co-combusted sludge in waste incinerator on heavy metals chemical speciation and environmental risk of horizontal flue ash. *Waste Management*, *102*, 645–654. https://doi.org/10.1016/j.wasman.2019.11.027

Chen, M., Blanc, D., Gautier, M., Mehu, J., & Gourdon, R. (2013). Environmental and technical assessments of the potential utilization of sewage sludge ashes (SSAs) as secondary raw materials in construction. *Waste Management*, *33*(5), 1268–1275. https://doi.org/10.1016/j.wasman.2013.01.004

Chen, Y. C., & Kuo, J. (2016). Potential of greenhouse gas emissions from sewage sludge management: A case study of Taiwan. *Journal of Cleaner Production*, *129*, 196–201. https://doi.org/10.1016/j.jclepro.2016.04.084

Chen, Y., Zhou, H., Tao, M., Cai, H., Tan, Z., & Li, X. (2019). Rapid analysis of sludge concentration using a microwave-assisted heating method: Parameters, modelling, and application. *Applied Thermal Engineering*, *152*(August 2018), 734–741. https://doi.org/10.1016/j.applthermaleng.2019.02.077

Chen, Z., Li, J. S., & Poon, C. S. (2018). Combined use of sewage sludge ash and recycled glass cullet for the production of concrete blocks. *Journal of Cleaner Production*, *171*, 1447–1459. https://doi.org/10.1016/j.jclepro.2017.10.140

Chen, Z., & Poon, C. S. (2017a). Comparative studies on the effects of sewage sludge ash and fly ash on cement hydration and properties of cement mortars. *Construction and Building Materials*, *154*, 791–803. https://doi.org/10.1016/j.conbuildmat.2017.08.003

Chen, Z., & Poon, C. S. (2017b). Comparing the use of sewage sludge ash and glass powder in cement mortars. *Environmental Technology*, *38*(11), 1390–1398. https://doi.org/10.1080/09593330.2016.1230652

Cheng, W. N., Yi, H., Yu, C. F., Wong, H. F., Wang, G., Kwon, E. E., & Tsang, Y. F. (2019). Biorefining waste sludge from water and sewage treatment plants into eco-construction material. *Frontiers in Energy Research*, *7*(MAR), 1–9. https://doi.org/10.3389/fenrg.2019.00022

Chin, S. C., Kusbiantoro, A., Wong, Y. K., & Ahmad, S. W. (2016). Characterization Of Sewage Sludge Ash (SSA) In Cement Mortar. *ARPN Journal of Engineering and Applied Science*, *11*(4), 2242–2247.

Cong, X., Lu, S., Gao, Y., Yao, Y., Elchalakani, M., & Shi, X. (2020). Effects of microwave, thermomechanical and chemical treatments of sewage sludge ash on its early-age behavior as supplementary cementitious material. *Journal of Cleaner Production*, *258*, 120647. https://doi.org/10.1016/j.jclepro.2020.120647

Daniel, Y. O., Zakari, M., & Mohammed, D. H. Z. (2020). Compressive Strength of Concrete Using Different Curing Methods. *Journal of Social and Development Sciences*, *10*(3(S)), 30–38. https://doi.org/10.22610/jsds.v10i3(s).2983

de Azevedo Basto, P., Savastano Junior, H., & de Melo Neto, A. A. (2019). Characterization and pozzolanic properties of sewage sludge ashes (SSA) by electrical conductivity. *Cement and Concrete Composites*, *104*(July), 103410. https://doi.org/10.1016/j.cemconcomp.2019.103410

Dou, X., Chen, D., Hu, Y., Feng, Y., & Dai, X. (2017). Carbonization of heavy metal impregnated sewage sludge oriented towards potential co-disposal. *Journal of Hazardous Materials*, *321*, 132–145. https://doi.org/10.1016/j.jhazmat.2016.09.010

Durgasravanthi, S., & Kumar, M. K. (2019). Study of Concrete Properties under Acid Attacks. *International Journal of Trend in Scientific Research and Development*, *3*(5), 627–630. https://doi.org/https://doi.org/10.31142/ijtsrd26392

Eid, E. M., Hussain, A. A., Taher, M. A., Galal, T. M., Shaltout, K. H., & Sewelam, N. (2020). Sewage Sludge Application Enhances the Growth of Corchorus olitorius Plants and Provides a Sustainable Practice for Nutrient Recirculation in

Agricultural Soils. *Journal of Soil Science and Plant Nutrition*, *20*(1), 149–159. https://doi.org/10.1007/s42729-019-00113-z

Elmi, A., Al-Khaldy, A., & AlOlayan, M. (2020). Sewage sludge land application: Balancing act between agronomic benefits and environmental concerns. *Journal of Cleaner Production*, *250*, 119512. https://doi.org/10.1016/j.jclepro.2019.119512

Eskandari-Naddaf, H., & Kazemi, R. (2018). Experimental evaluation of the effect of mix design ratios on compressive strength of cement mortars containing cement strength class 42.5 and 52.5 MPa. *Procedia Manufacturing*, *22*, 392–398. https://doi.org/10.1016/j.promfg.2018.03.060

Falciglia, P. P., Roccaro, P., Bonanno, L., De Guidi, G., Vagliasindi, F. G. A., & Romano, S. (2018). A review on the microwave heating as a sustainable technique for environmental remediation/detoxification applications. *Renewable and Sustainable Energy Reviews*, *95*(March), 147–170. https://doi.org/10.1016/j.rser.2018.07.031

Fijalkowski, K., Rorat, A., Grobelak, A., & Kacprzak, M. J. (2017). The presence of contaminations in sewage sludge – The current situation. *Journal of Environmental Management*, *203*, 1126–1136. https://doi.org/10.1016/j.jenvman.2017.05.068

Fontes, C. M. A., Toledo Filho, R. D., & Barbosa, M. C. (2016). Sewage sludge ash (SSA) in high performance concrete: characterization and application. *Revista IBRACON de Estruturas e Materiais*, *9*(6), 989–1006. https://doi.org/10.1590/s1983-41952016000600009

Gil, A., Siles, J. A., Toledo, M., & Martín, M. A. (2019). Effect of microwave pretreatment on centrifuged and floated sewage sludge derived from wastewater treatment plants. *Process Safety and Environmental Protection*, *128*, 251–258. https://doi.org/10.1016/j.psep.2019.05.053

Grobelak, A., Grosser, A., Kacprzak, M., & Kamizela, T. (2019). Sewage sludge processing and management in small and medium-sized municipal wastewater treatment plant-new technical solution. *Journal of Environmental Management*, *234*(October 2018), 90–96. https://doi.org/10.1016/j.jenvman.2018.12.111

Hadigheh, S. A., Gravina, R. J., & Smith, S. T. (2017). Effect of acid attack on FRP-to-concrete bonded interfaces. *Construction and Building Materials*, *152*, 285–303. https://doi.org/10.1016/j.conbuildmat.2017.06.140

Hanum, F., Yuan, L. C., Kamahara, H., Aziz, H. A., Atsuta, Y., Yamada, T., & Daimon, H. (2019). Treatment of sewage sludge using anaerobic digestion in Malaysia: Current state and challenges. *Frontiers in Energy Research*, *7*(MAR), 1–7. https://doi.org/10.3389/fenrg.2019.00019

Hasan, M. A., Ashraf, M. A., & Mahmud, M. I. H. (2017). Study On Concrete Compressive Strength Based On Specimen. *Journal of Science and Technology*, *15*(June), 61–64.

Healy, M., Fenton, O., Cummins, E., Clarke, R., Peyton, D., Fleming, G., Wall, D., Morrison, L., & Cormican, M. (2017). *Health and Water Quality Impacts arising* *from land spreading of biosolids* (Issue 200).

Herki, B. M. A. (2020). Effect of different curing regimes on capillarity of concrete incorporating local materials. *Journal of Critical Reviews*, *7*(4), 524–530. https://doi.org/10.31838/jcr.07.04.98

Hiremath, P. N., & Yaragal, S. C. (2017). Effect of different curing regimes and durations on early strength development of reactive powder concrete. *Construction and Building Materials*, *154*, 72–87. https://doi.org/10.1016/j.conbuildmat.2017.07.181

Hossain, M. M., Karim, M. R., Hasan, M., Hossain, M. K., & Zain, M. F. M. (2016). Durability of mortar and concrete made up of pozzolans as a partial replacement of cement: A review. *Construction and Building Materials*, *116*, 128–140. https://doi.org/10.1016/j.conbuildmat.2016.04.147

Huang, Y. F., Kuan, W. H., & Chang, C. Y. (2018). Effects of particle size, pretreatment, and catalysis on microwave pyrolysis of corn stover. *Energy*, *143*, 696–703. https://doi.org/10.1016/j.energy.2017.11.022

Ing, D. S., Chin, S. C., Guan, T. K., & Suil, A. (2016). The Use Of Swage Sludge Ash (SSA) As Partial Replacement Of Cement In Concrete. *ARPN Journal of Engineering and Applied Science*, *11*(6), 3771–3775.

Ioannis K. Kalavrouziotis, P. K. (2016). Wastewater and Sludge Reuse Management in Agriculture. *Journal of Environmental Quality*, *20*, 1–13. https://doi.org/10.6092/issn.2281-4485/6303

Ismail, S., Kwan, W. H., & Ramli, M. (2017). Mechanical strength and durability properties of concrete containing treated recycled concrete aggregates under different curing conditions. *Construction and Building Materials*, *155*, 296–306. https://doi.org/10.1016/j.conbuildmat.2017.08.076

Jagaba, A. H., Shuaibu, A., Umaru, I., Musa, S., Lawal, I. M., & Abubakar, S. (2019). Stabilization of Soft Soil by Incinerated Sewage Sludge Ash from Municipal Wastewater Treatment Plant for Engineering Construction. *Sustainable Structure and Materials*, *2*(1), 32–44. https://doi.org/10.26392/SSM.2019.02.01.032

Jain, A. (2017). *United Nation Summary Report Waste Management in ASEAN Countries*.

Jaya, R. P., Wan, C. N. C., Hainin, M. R., Warid, M. N. M., Ibrahim, M. H. W., Nazri, F. M., & Arshad, M. F. (2018). Strength properties of rice husk ash concrete under sodium sulphate attack. *International Journal of Integrated Engineering*, *10*(4), 199–202.

Joseph, A. M., Snellings, R., Van den Heede, P., Matthys, S., & De Belie, N. (2018). The use of municipal solidwaste incineration ash in various building materials: A Belgian point of view. *Materials*, *11*(1). https://doi.org/10.3390/ma11010141

Jurowski, K., & Grzeszczyk, S. (2018). Influence of selected factors on the relationship between the dynamic elastic modulus and compressive strength of concrete.

Materials, *11*(4), 1–12. https://doi.org/10.3390/ma11040477

Kacprzak, M., Neczaj, E., Fijałkowski, K., Grobelak, A., Grosser, A., Worwag, M., Rorat, A., Brattebo, H., Almås, Å., & Singh, B. R. (2017). Sewage sludge disposal strategies for sustainable development. *Environmental Research*, *156*(June 1986), 39–46. https://doi.org/10.1016/j.envres.2017.03.010

Kaewunruen, S., Wu, L., Goto, K., & Najih, Y. M. (2018). Vulnerability of structural concrete to extreme climate variances. *Climate*, *6*(2), 1–13. https://doi.org/10.3390/cli6020040

Kaminskas, R., Kubiliute, R., & Prialgauskaite, B. (2020). Smectite clay waste as an additive for Portland cement. *Cement and Concrete Composites*, *113*(May), 103710. https://doi.org/10.1016/j.cemconcomp.2020.103710

Kapusta, K. (2018). Effect of ultrasound pretreatment of municipal sewage sludge on characteristics of bio-oil from hydrothermal liquefaction process. *Waste Management*, *78*, 183–190. https://doi.org/10.1016/j.wasman.2018.05.043

Khodabakhshian, A., Ghalehnovi, M., de Brito, J., & Asadi Shamsabadi, E. (2018). Durability performance of structural concrete containing silica fume and marble industry waste powder. *Journal of Cleaner Production*, *170*, 42–60. https://doi.org/10.1016/j.jclepro.2017.09.116

Kocab, D., Kucharczykova, B., Misak, P., Zitt, P., & Kralikova, M. (2017). Development of the Elastic Modulus of Concrete under Different Curing Conditions. *Procedia Engineering*, *195*, 96–101. https://doi.org/10.1016/j.proeng.2017.04.529

Krejcirikova, B., Ottosen, L. M., Kirkelund, G. M., Rode, C., & Peuhkuri, R. (2019a). Characterization of sewage sludge ash and its effect on moisture physics of mortar. *Journal of Building Engineering*, *21*(October 2018), 396–403. https://doi.org/10.1016/j.jobe.2018.10.021

Krejcirikova, B., Ottosen, L. M., Kirkelund, G. M., Rode, C., & Peuhkuri, R. (2019b). Characterization of sewage sludge ash and its effect on moisture physics of mortar. *Journal of Building Engineering*, *21*(May 2018), 396–403. https://doi.org/10.1016/j.jobe.2018.10.021

Kumar, V., Chopra, A. K., & Kumar, A. (2017). A Review on Sewage Sludge (Biosolids) a Resource for Sustainable Agriculture. *Archives of Agriculture and Environmental Science*, *2*(4), 340–347. https://doi.org/10.26832/24566632.2017.020417

Lau, P. C., Teo, D. C. L., & Mannan, M. A. (2017). Characteristics of lightweight aggregate produced from lime-treated sewage sludge and palm oil fuel ash. *Construction and Building Materials*, *152*, 558–567. https://doi.org/10.1016/j.conbuildmat.2017.07.022

Lau, P. C., Teo, D. C. L., & Mannan, M. A. (2018). Mechanical, durability and microstructure properties of lightweight concrete using aggregate made from lime-treated sewage sludge and palm oil fuel ash. *Construction and Building Materials*, *176*, 24–34. https://doi.org/10.1016/j.conbuildmat.2018.04.179

Lee, M., & Kim, D. (2017). Identification of phosphorus forms in sewage sludge ash during acid pre-treatment for phosphorus recovery by chemical fractionation and spectroscopy. *Journal of Industrial and Engineering Chemistry*, *51*, 64–70. https://doi.org/10.1016/j.jiec.2017.02.013

Li, J., Chen, Z., Wang, Q., Fang, L., Xue, Q., Cheeseman, C. R., & Donatello, S. (2018). Change in re-use value of incinerated sewage sludge ash due to chemical extraction of phosphorus. *Waste Management*, *74*, 404–412. https://doi.org/10.1016/j.wasman.2018.01.007

Li, J. S., Guo, M. Z., Xue, Q., & Poon, C. S. (2017). Recycling of incinerated sewage sludge ash and cathode ray tube funnel glass in cement mortars. *Journal of Cleaner Production*, *152*, 142–149. https://doi.org/10.1016/j.jclepro.2017.03.116

Li, X., He, C., Lv, Y., Jian, S., Liu, G., Jiang, W., & Jiang, D. (2020). Utilization of municipal sewage sludge and waste glass powder in production of lightweight aggregates. *Construction and Building Materials*, *256*, 119413. https://doi.org/10.1016/j.conbuildmat.2020.119413

Liu, Minghao, Zhao, Y., Xiao, Y., & Yu, Z. (2019). Performance of cement pastes containing sewage sludge ash at elevated temperatures. *Construction and Building Materials*, *211*, 785–795. https://doi.org/10.1016/j.conbuildmat.2019.03.290

Liu, Minghao, Zhao, Y., & Yu, Z. (2021). Effects of sewage sludge ash produced at different calcining temperatures on pore structure and durability of cement mortars. *Journal of Material Cycles and Waste Management*, *23*(2), 755–763. https://doi.org/10.1007/s10163-021-01174-y

Liu, Mingwei, Wang, C., Bai, Y., & Xu, G. (2018). Effects of sintering temperature on the characteristics of lightweight aggregate made from sewage sludge and river sediment. *Journal of Alloys and Compounds*, *748*, 522–527. https://doi.org/10.1016/j.jallcom.2018.03.216

Liu, W., Iordan, C. M., Cherubini, F., Hu, X., & Fu, D. (2020). Environmental impacts assessment of wastewater treatment and sludge disposal systems under two sewage discharge standards: A case study in Kunshan, China. *Journal of Cleaner Production*, *xxxx*, 125046. https://doi.org/10.1016/j.jclepro.2020.125046

Lynn, C. J., Dhir, R. K., & Ghataora, G. S. (2018a). Environmental impacts of sewage sludge ash in construction: Leaching assessment. *Resources, Conservation and Recycling*, *136*(April), 306–314. https://doi.org/10.1016/j.resconrec.2018.04.029

Lynn, C. J., Dhir, R. K., & Ghataora, G. S. (2018b). Environmental impacts of sewage sludge ash in construction: Leaching assessment. *Resources, Conservation and Recycling*, *136*(May), 306–314. https://doi.org/10.1016/j.resconrec.2018.04.029

Mailar, G., N, S. R., B.M, S., D.S, M., Hiremath, P., & K., J. (2016). Investigation of concrete produced using recycled aluminium dross for hot weather concreting conditions. *Resource-Efficient Technologies*, *2*(2), 68–80. https://doi.org/10.1016/j.reffit.2016.06.006

Manoj Kumar, G., Uthranarayan, C., Joseph Jebaraj, D. J., Keerthana, S., & Ganesh, N. (2019). Exploration of tensile, flexural and hardness test properties of prosopis juliflora / glass / epoxy hybrid composite laminates. *Journal of Physics: Conference Series*, *1362*(1). https://doi.org/10.1088/1742-6596/1362/1/012015

Meisuh, B. K., Kankam, C. K., & Buabin, T. K. (2018). Effect of quarry rock dust on the flexural strength of concrete. *Case Studies in Construction Materials*, *8*(November 2017), 16–22. https://doi.org/10.1016/j.cscm.2017.12.002

Mohammadhosseini, H., Tahir, M. M., Mohd Sam, A. R., Abdul Shukor Lim, N. H., & Samadi, M. (2018). Enhanced performance for aggressive environments of green concrete composites reinforced with waste carpet fibers and palm oil fuel ash. *Journal of Cleaner Production*, *185*, 252–265. https://doi.org/10.1016/j.jclepro.2018.03.051

Monteiro, P. J. M., Miller, S. A., & Horvath, A. (2017). Towards sustainable concrete. *Nature Materials*, *16*(7), 698–699. https://doi.org/10.1038/nmat4930

Muthusamy, K., Fadzil, M. Y., Muhammad Nazrin Akmal, A. Z., Wan Ahmad, S., Nur Azzimah, Z., Mohd Hanafi, H., & Mohamad Hafizuddin, R. (2018). Effect of fly ash content towards Sulphate resistance of oil palm shell lightweight aggregate concrete. *IOP Conference Series: Materials Science and Engineering*, *342*(1). https://doi.org/10.1088/1757-899X/342/1/012105

Naamane, S., Rais, Z., Taleb, M., Mtarfi, N. H., & Sfaira, M. (2016). Sewage sludge ashes : Application in construction materials. *Journal of Material Environment Science*, *7*(1), 67–72.

Najjar, M. F., Nehdi, M. L., Soliman, A. M., & Azabi, T. M. (2017). Damage mechanisms of two-stage concrete exposed to chemical and physical sulfate attack. *Construction and Building Materials*, *137*, 141–152. https://doi.org/10.1016/j.conbuildmat.2017.01.112

Naqi, A., Siddique, S., Kim, H. K., & Jang, J. G. (2020). Examining the potential of calcined oyster shell waste as additive in high volume slag cement. *Construction and Building Materials*, *230*, 116973. https://doi.org/10.1016/j.conbuildmat.2019.116973

Nazierah, M. Y. N., Kartini, K., Hamidah, M. S., & Nuraini, T. (2016). Compressive Strength and Water Absorption of Sewage Sludge Ash (SSA) Mortar. *InCIEC 2015*, 199–207. https://doi.org/10.1007/978-981-10-0155-0

Neamitha, M., & Supraja, T. M. (2017). Influence of Water Cement Ratio and The Size of Aggregate on The Properties Of Pervious Concrete. *International Refereed Journal of Engineering and Science*, *6*(4), 2319–183. http://www.irjes.com/Papers/vol6-issue4/Version-2/B6420916.pdf

Neczaj, E., Fija, K., Grobelak, A., & Grosser, A. (2017). Sewage sludge disposal strategies for sustainable development. *Environmental Research*, *156*(June 1986), 39–46. https://doi.org/10.1016/j.envres.2017.03.010

Nur-Nazirah, P. M., Arifin, A., Shamshuddin, J., Rezaul, K., Muhammad-Nazrin, Mohd-Hadi, A., & Aiza-Shaliha. (2017). Evaluation of Ricinus communis as a phytoremediator of manganese in soil contaminated with sewage sludge. *Pertanika Journal of Tropical Agricultural Science*, *40*(3), 425–434.

Ogork, E., & Ibrahim, T. (2016). Properties of Cement Paste and Concrete Containing Calcium Carbide Waste As Additive. *Nigerian Journal of Technology*, *36*(1), 26–31. https://doi.org/10.4314/njt.v36i1.4

Ogunjuyigbe, A. S. O., Ayodele, T. R., & Alao, M. A. (2017). Electricity generation from municipal solid waste in some selected cities of Nigeria: An assessment of feasibility, potential and technologies. *Renewable and Sustainable Energy Reviews*, *80*(May 2016), 149–162. https://doi.org/10.1016/j.rser.2017.05.177

Oliva, M., Vargas, F., & Lopez, M. (2019). Designing the incineration process for improving the cementitious performance of sewage sludge ash in Portland and blended cement systems. *Journal of Cleaner Production*, *223*, 1029–1041. https://doi.org/10.1016/j.jclepro.2019.03.147

Ostrowski, K., Sadowski, Ł., Stefaniuk, D., Wałach, D., Gawenda, T., Oleksik, K., & Usydus, I. (2018). The effect of the morphology of coarse aggregate on the properties of self-compacting high-performance fibre-reinforced concrete. *Materials*, *11*(8). https://doi.org/10.3390/ma11081372

Ottosen, L. M., Olsen, R. J., & Hansen, E. Ø. (2017). Preliminary Investigation On Use Of Sewage Sludge Ash As Partly Cement Replacement In Lightweight Aggregate Concrete. *Academic Journal of Civil Engineering*, *35*(2), 581–587.

Owaid, H. M., Majeed, Z. H., Jawad, I. T., & Hamid, R. B. (2016). *Utilization of alum sludge as pozzolanic material in sustainable high performance concrete*. *September*.

Paul, S. C., van Zijl, G. P. A. G., & Šavija, B. (2020). Effect of fibers on durability of concrete: A practical review. *Materials*, *13*(20), 1–26. https://doi.org/10.3390/ma13204562

Pepejal, J. P. S. (2017). *JPSPN Statistik Kategori Tapak Pelupusan Sisa Pepejal Mengikut Negeri Tahun 2015 - Statistik Kategori Tapak Pelupusan Sisa Pepejal Mengikut Negeri Tahun 2015 - MAMPU*. http://www.data.gov.my/data/ms_MY/dataset/jpspn-statistik-kategori-tapak-pelupusan-sisa-pepejal-mengikut-negeri-tahun-2015/resource/3ecaa73e-f184-47dc-a948-dd381dd14118

Pham, T. M., Elchalakani, M., Hao, H., Lai, J., Ameduri, S., & Tran, T. M. (2019). Durability characteristics of lightweight rubberized concrete. *Construction and Building Materials*, *224*, 584–599. https://doi.org/10.1016/j.conbuildmat.2019.07.048

Philip, J., Ismail, M. A. K., & Al-Subari, B. (2019). Strength and sulphate resistance of high performance concrete containing different fineness of Palm oil fuel ash. *IOP Conference Series: Materials Science and Engineering*, *495*(1). https://doi.org/10.1088/1757-899X/495/1/012100

Piasta, W., & Zarzycki, B. (2017). The effect of cement paste volume and w/c ratio on shrinkage strain, water absorption and compressive strength of high performance concrete. *Construction and Building Materials*, *140*, 395–402. https://doi.org/10.1016/j.conbuildmat.2017.02.033

Rabie, G. M., El-Halim, H. A., & Rozaik, E. H. (2019). Influence of using dry and wet wastewater sludge in concrete mix on its physical and mechanical properties. *Ain Shams Engineering Journal*, *10*(4), 705–712. https://doi.org/10.1016/j.asej.2019.07.008

Raheem, A., Sikarwar, V. S., He, J., Dastyar, W., Dionysiou, D. D., Wang, W., & Zhao, M. (2018). Opportunities and challenges in sustainable treatment and resource reuse of sewage sludge: A review. *Chemical Engineering Journal*, *337*(October 2017), 616–641. https://doi.org/10.1016/j.cej.2017.12.149

Rashwan, M. A., Al - Basiony, T. M., Mashaly, A. O., & Khalil, M. M. (2020). Behaviour of fresh and hardened concrete incorporating marble and granite sludge as cement replacement. *Journal of Building Engineering*, *32*(May), 101697. https://doi.org/10.1016/j.jobe.2020.101697

Reddy Babu, G., Madhusudana Reddy, B., & Venkata Ramana, N. (2018). Quality of mixing water in cement concrete "a review. *Materials Today: Proceedings*, *5*(1), 1313–1320. https://doi.org/10.1016/j.matpr.2017.11.216

Ren, J., Zhang, L., & San Nicolas, R. (2020). Degradation process of alkali-activated slag/fly ash and Portland cement-based pastes exposed to phosphoric acid. *Construction and Building Materials*, *232*, 117209. https://doi.org/10.1016/j.conbuildmat.2019.117209

Rezaee, F., Danesh, S., Tavakkolizadeh, M., & Mohammadi-Khatami, M. (2019). Investigating chemical, physical and mechanical properties of eco-cement produced using dry sewage sludge and traditional raw materials. *Journal of Cleaner Production*, *214*, 749–757. https://doi.org/10.1016/j.jclepro.2018.12.153

Safer, O., Belas, N., Belaribi, O., Belguesmia, K., Bouhamou, N. E., & Mebrouki, A. (2018). Valorization of Dredged Sediments as a Component of Vibrated Concrete: Durability of These Concretes Against Sulfuric Acid Attack. *International Journal of Concrete Structures and Materials*, *12*(1). https://doi.org/10.1186/s40069-018-0270-7

Safuan Zakaria, M., Hassan, S., Faizairi, M., & Noor, M. (2018). Thermal Degradation of Malaysian Domestic Wastewater Sludge (DWS) Using Thermogravimetric Analysis Method. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences Journal Homepage*, *48*, 176–182. www.akademiabaru.com/arfmts.html

Safuan Zakaria, M., Hassan, S., & Noor, M. F. M. (2018). Thermal degradation of Malaysian Domestic Wastewater Sludge (DWS) using thermogravimetric analysis method. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *48*(2), 176–182.

Sairam Kumar, N. V. (2020). Performance of crushed rock dust concrete exposed to sulphuric and hydrochloric acid solutions. *IOP Conference Series: Materials*

Science and Engineering, 1–9. https://doi.org/10.1088/1757-899X/988/1/012021

Silva, R. V., De Brito, J., & Dhir, R. K. (2016). Establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete. *Journal of Cleaner Production*, *112*, 2171–2186. https://doi.org/10.1016/j.jclepro.2015.10.064

Siregar, A. P. N., Rafiq, M. I., & Mulheron, M. (2017). Experimental investigation of the effects of aggregate size distribution on the fracture behaviour of high strength concrete. *Construction and Building Materials*, *150*, 252–259. https://doi.org/10.1016/j.conbuildmat.2017.05.142

Stawiski, B., & Kania, T. (2019). Examining the distribution of strength across the thickness of reinforced concrete elements subject to sulphate corrosion using the ultrasonic method. *Materials*, *12*(16), 1–16. https://doi.org/10.3390/ma12162519

Sulaiman, M. A., Ali, M. I., Al-Amri, M. Y., Muthusamy, K., Albshir Budiea, A. M., Nordin, N., Duraisamy, Y., & Othman, R. (2020). Properties of Concrete Containing Crushed Palm Oil Clinker as Partial Fine Aggregate Replacement. *Materials Science and Engineering*, *712*(1). https://doi.org/10.1088/1757-899X/712/1/012020

Świerczek, L., Cieślik, B. M., & Konieczka, P. (2021). Challenges and opportunities related to the use of sewage sludge ash in cement-based building materials – A review. *Journal of Cleaner Production*, *287*. https://doi.org/10.1016/j.jclepro.2020.125054

Taheri, S., Delgado, G. P., Agbaje, O. B. A., Giri, P., & Clark, S. M. (2020). Corrosion Inhibitory Effects of Mullite in Concrete Exposed to Sulfuric Acid Attack. *Corrosion and Materials Degradation*, *1*(2), 282–295. https://doi.org/10.3390/cmd1020014

Teoh, S. K., & Li, L. Y. (2020). Feasibility of alternative sewage sludge treatment methods from a lifecycle assessment (LCA) perspective. *Journal of Cleaner Production*, *247*, 119495. https://doi.org/10.1016/j.jclepro.2019.119495

Tian, Y., Jin, N., & Jin, X. (2018). Coupling effect of temperature and relative humidity diffusion in concrete under ambient conditions. *Construction and Building Materials*, *159*, 673–689. https://doi.org/10.1016/j.conbuildmat.2017.10.128

Tibbetts, C. M., Perry, M. C., Ferraro, C. C., & Hamilton, H. R. (2018). Aggregate correction factors for concrete elastic modulus prediction. *ACI Structural Journal*, *115*(4), 931–941. https://doi.org/10.14359/51701914

Trusilewicz, L. N., Nocuń-Wczelik, W., Górak, P., & Woyciechowski, P. (2019). Early hydration calorimetric study of the sewage sludge incinerated waste streams Portland cement-based binders: technological implications. *Journal of Thermal Analysis and Calorimetry*, *138*(4), 2955–2967. https://doi.org/10.1007/s10973-019-08784-7

Umara, A., Warid, M., & Ahmad, Y. (2016). Effect Of Hydrochloric acid On Concrete. *Jurnal Teknologi(Sciences & Engineering)*, *6–12*(78), 31–36.

Vouk, D., Nakic, D., Stirmer, N., & Cheeseman, C. R. (2017). Use of sewage sludge ash in cementitious materials. *Reviews on Advanced Materials Science*, *49*(2), 158–170.

Vouk, Drazen, Nakic, D., Stirmer, N., & Cheeseman, C. (2018). Influence of combustion temperature on the performance of sewage sludge ash as a supplementary cementitious material. *Journal of Material Cycles and Waste Management*, *20*(3), 1458–1467. https://doi.org/10.1007/s10163-018-0707-8

Wang, J., Liu, E., & Li, L. (2019). Characterization on the recycling of waste seashells with Portland cement towards sustainable cementitious materials. *Journal of Cleaner Production*, *220*, 235–252. https://doi.org/10.1016/j.jclepro.2019.02.122

Wang, Z., Xie, L., Liu, K., Wang, J., Zhu, H., Song, Q., & Shu, X. (2019). Co-pyrolysis of sewage sludge and cotton stalks. *Waste Management*, *89*, 430–438. https://doi.org/10.1016/j.wasman.2019.04.033

Wojciech, P., & Monika, L. (2016). The Effect of Sewage Sludge Ash On Properties of Cement Composites. *Procedia Engineering*, *161*, 1018–1024. https://doi.org/10.1016/j.proeng.2016.08.842

Yi, Y., Zhu, D., Guo, S., Zhang, Z., & Shi, C. (2020). A review on the deterioration and approaches to enhance the durability of concrete in the marine environment. *Cement and Concrete Composites*, *113*(May), 103695. https://doi.org/10.1016/j.cemconcomp.2020.103695

Yusuf, R. O., Noor, Z. Z., Din, M. F. M. d., & Abba, A. H. (2012). Use of sewage sludge ash (SSA) in the production of cement and concrete - A review. *International Journal of Global Environmental Issues*, *12*(2–4), 214–228. https://doi.org/10.1504/IJGENVI.2012.049382

Zhang, H., Rigamonti, L., Visigalli, S., Turolla, A., Gronchi, P., & Canziani, R. (2019). Environmental and economic assessment of electro-dewatering application to sewage sludge: A case study of an Italian wastewater treatment plant. *Journal of Cleaner Production*, *210*, 1180–1192. https://doi.org/10.1016/j.jclepro.2018.11.044

Zhou, G., Gu, Y., Yuan, H., Gong, Y., & Wu, Y. (2020). Selecting sustainable technologies for disposal of municipal sewage sludge using a multi-criterion decision-making method: A case study from China. *Resources, Conservation and Recycling*, *161*(April), 104881. https://doi.org/10.1016/j.resconrec.2020.104881

Zhou, Y. fan, Li, J. shan, Lu, J. xin, Cheeseman, C., & Poon, C. S. (2020a). Recycling incinerated sewage sludge ash (ISSA) as a cementitious binder by lime activation. *Journal of Cleaner Production*, *244*, 118856. https://doi.org/10.1016/j.jclepro.2019.118856

Zhou, Y. fan, Li, J. shan, Lu, J. xin, Cheeseman, C., & Poon, C. S. (2020b). Sewage sludge ash: A comparative evaluation with fly ash for potential use as lime-pozzolan binders. *Construction and Building Materials*, *242*, 118160.