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The Feasibility of Recycling Gypsum Waste

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Abstract
The tremendous development in various industries has brought on concerns related to environmental pollution and human health. Wastewater treatment activities in the chemical industry have generated approximately 50,000 tons of gypsum waste per month. Heavy metals released from the uncontrolled dumping of gypsum waste in landfills might be harmful to the environment and humans since it may leach into soil and groundwater. Therefore, landfilling is no longer an appropriate method for disposing waste due to the leaching potential of gypsum. On the other hand, secure landfills which are more suitable for the disposal of gypsum waste is very costly for the industry. Hence, recycling industrial gypsum waste with different applications will be beneficial in terms of saving landfill area and reducing the cost needed for disposing waste.

Keywords: *gypsum waste, toxic waste, heavy metal, recycling*

I. INTRODUCTION

Gypsum has attracted particular interest due to huge quantities generated by different industries. According to the United States Geological Survey, the production of gypsum in 2016 was 17 million tons and it is predicted to increase in subsequent years [1]. Based on the type industrial processing products, various types of gypsum waste is produced such as phosphogypsum (a byproduct from phosphoric acid making), flue gas desulfurized gypsum (a byproduct produced by coal-fueled power plants), fluorgypsum (a byproduct after fluorspar is converted to hydrofluoric acid) and citrogyspum (a by-product from the production of citric acid). Nevertheless, gypsum waste from acid plants is currently being dumped in landfills and this not only endangers the environment, but also human health.

Besides that, the Department of Environment (DOE) of Malaysia classifies gypsum waste generated by the chemical industry or power plant activities as scheduled waste [2]. Generally, scheduled waste refers to any waste that is listed in the First Schedule, Environmental Quality by DOE according to Regulation 2005. In particular, any waste that contains toxic and dangerous characteristics which will affect the environment and public health is also defined as scheduled waste. At present, most of the gypsum waste in Malaysia falls under Environmental Quality Regulations 2005 and is classified as group number two (SW 205) which is described as a byproduct that is high in heavy metal content such as aluminum, copper, chromium, lead, tin, zinc, nickel, vanadium, cadmium and beryllium [2]. Fig. 1 shows an example of gypsum sludge in filter cake form.

Fig. 1.: Gypsum sludge

In China, gypsum sludge containing small amounts of arsenic (As) was sent to landfills for disposal [3]. The As ions are unstable and can easily be mobilized into soil by water. Thus, a different approach is required to manage the disposal of gypsum sludge. In addition, there is a significant concern on the impact of heavy metal leaching which will end up accumulated in drains, rivers and waterways. This is because heavy metal leaching might cause pollution, groundwater contamination and pose a risk to public health. Besides, due to its fine particle size, gypsum is difficult to pelletize and has to be bonded with particular additives.

On top of that, disposing gypsum waste in landfills may cause the leaching of heavy metal elements into soil and groundwater as gypsum waste contains a number of toxic elements such as zinc, manganese, lead, chromium, cadmium and nickel [4-6]. Inorganic contaminants are always a main concern for any type of gypsum, especially heavy metals, because they require specific treatment to prevent environmental pollution. Most gypsum waste was found to be contained high concentrations of accumulated heavy metals. Besides that, the abundance of gypsum waste generated by wastewater treatment processes had to be disposed of in secure landfills which can be very costly due to transportation and management processes. Moreover, gypsum waste tends to carry toxic heavy metals and radioactive contamination. Thus, special landfills could be an efficient and viable disposal method but they are costly as many procedures and equipment are involved [7-10]. Gypsum waste is commonly disposed of in special landfills which could be problematic from an environmental perspective due to the decrease in available areas and high disposal costs. Moreover, the effects on air quality as well as groundwater and surface water pollution caused by the disposal of gypsum waste in landfill sites are of great concern to the government. Hence, an alternative method for gypsum waste disposal needs to be sought in order to replace special landfill areas with more environmentally-friendly methods [11-13]. Therefore, more researchers are encouraged to reuse gypsum waste in new products in order to help conserve the environment.

II. GENERATION OF GYPSUM WASTE

As stated in Gypsum Recycling International, millions of tons of gypsum waste are disposed of every year in the USA and in Asia. The stockpile of gypsum waste dumped in landfills releases hazardous gases, which result in environmental pollution. In Japan, three workers died in 1999 because of exposure to hydrogen sulfide (H2S) in landfill sites reported by [15]. Hydogen sulfide gas cannot be seen by the naked eye but it is very dangerous. There is no proper installation of gas pipes or leachate and water treatment facilities such as liners prepared for gypsum waste dumped in landfills. The H2S gas generated comes from sulfate (SO4) consumed and converted by sulfate-reducing bacteria (SRB) under anaerobic conditions [16]. Gypsum boards are construction debris which mainly consists of gypsum (CaSO4). Furthermore, according to [17], the Japanese government acknowledged that gypsum board contains H2S, thereby making the dumping of gypsum waste into landfills illegal [18].

Prior to that, tons of gypsum sludge were produced as by products of chemical and

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industrial wastewater treatment [19]. The chemical processes of different types of acid are the main factors of gypsum waste generation. The desulphurization procedure for power stations to release flue gases is one of the activities that contribute to the production of gypsum waste. The quantity of gypsum waste generated increases every year in Malaysia and it is anticipated to grow due to the rapid development in the chemical industry and power plants. Approximately 1.6 million metric tons of industrial sludge is produced annually while 0.81 million metric tons of industrial sludge is disposed of at sanitary landfills [20].

According to [21], during the treatment of acid main drainage, gypsum sludge is produced as a byproduct of alkaline treatment. Eventually, the sludge can lead to the contamination of groundwater and negatively affect the surrounding air quality. However, the disposal of gypsum waste in a secure landfill requires many procedures which can be very costly for the industry.

Furthermore, wastewater treatment activities from the chemical industry and power plants have resulted in high quantities of gypsum waste being generated in Malaysia. This has become a great concern to the environment and human health. Wastewater treatment from the bleaching earth industry produces gypsum through the dilution of sulphuric acid during the neutralization process. This is a classic example of a neutralization reaction where acid and alkali react to form salt (gypsum) and water. Gypsum generation in the wastewater treatment process is shown in (1):

$$H_2SO_4 + Ca(OH)_2 \rightarrow \quad + H_2O \qquad (1)$$

Sulphuric acid Calcium hydroxide Hydrated

The gypsum produced is then sent to a secure landfill. Generally, gypsum waste is obtained as a filter cake in the form of fine particles. It is wet as it contains about 18% to 50% of water. Gypsum waste also requires the use of specialized binders and additives for pelletization to occur. Moreover, in bulk form, gypsum contains high moisture content which makes it difficult to manage. Stockpiled gypsum is hard to store and transport. Fig. 2 shows the wastewater treatment process in the chemical industry:

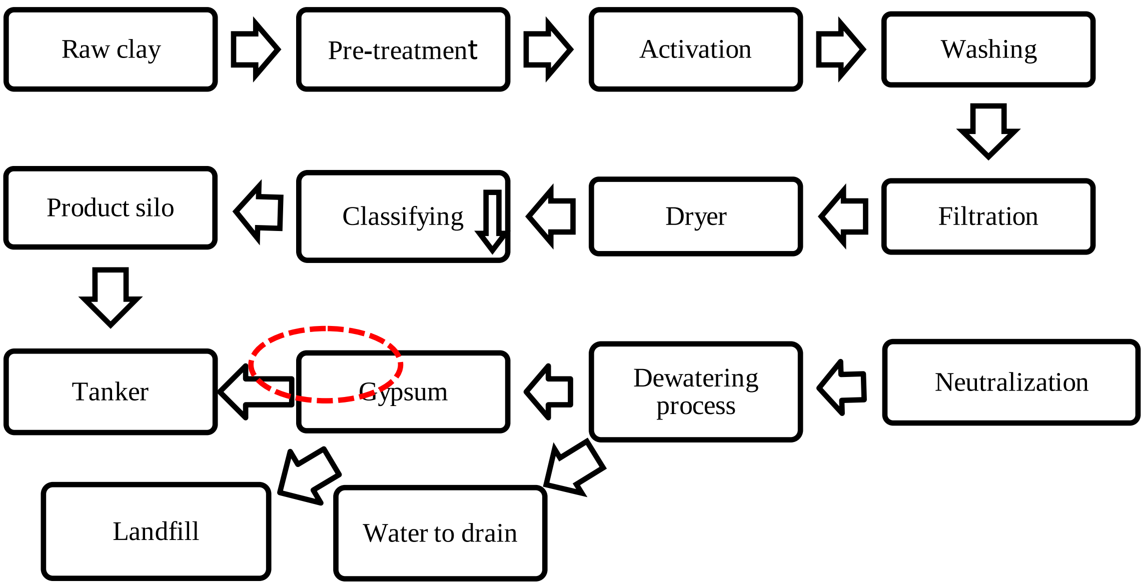

Fig.2.: The wastewater treatment process in the chemical industry

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III. GYPSUM WASTE RECYCLING

In recent decades, the interest in finding alternatives for the utilization of gypsum waste generated from industrial wastewater treatment activities has ascended. A possible method that could replace costly landfills is to convert gypsum waste into new types of products that would be conceivable and useful. For that reason, special attention needs to be paid to inorganic contents in gypsum waste before it is dumped away. Specific treatment methods for preventing environmental pollution during the disposal process have cost various industries a lot of money. Hence, various approaches have been proposed to improve gypsum waste management. Therefore, gypsum waste is now widely used in plaster cement production which acts as natural cement replacement, manufacturing of boards, construction of roads, treatment of sulfuric acid and ammonium sulfate and as fertilizer for saline-alkali soils in accordance with particular guidelines [22-25].

In [26], natural gypsum ores were replaced with recycled dihydrated gypsum. The recycled dihyrated gypsum needed large amounts of water because of a wider exposed area, distributed particle size, poor sphericity and porosity. The strength test showed decreased values as porosity increases. The evaporation of water causes ettringite to form within the particles. It is closely related to flexural strength as the process of dihydrated gypsum forming recycled hemihydrate will change the crystal morphology to the sphericity of the shape .

Based on [27], gypsum is a fire resistant material that can function as fire protection in building construction. Load bearing structures have widely utilized gypsum plaster for fire protection. Besides that, the use of gypsum as one of the most environmentally-friendly binders in building materials is getting more attention. Unfortunately, gypsum loses its mechanical strength when it is in a wet condition. In order to make gypsum more stable, endothermic decomposition during the firing process will change the composition of calcium sulphate dihydrate and remove the water of crystallization. A temperature of up to 1000°C can be achieved by gypsum compared to other materials that are only able to withstand temperatures up to 200°C.

According to [28], the potential of gypsum for binding soil particles was tested. The results showed that in a dry environment, the strength of soil mixtures containing gypsum increases. However, it is a challenge to use gypsum as a soil stabilizer because of its water soluble characteristic. According to [29-31], before gypsum was incorporated into ground improvement projects, a specific solidification agent is required to bind with the gypsum particles to enhance the stability and durability of the ground. Moreover, gypsum sludge contains a lot of important elements such as calcium sulfate which has the potential to be used as a binder for arsenic sludge treatment. Moving forward, the compressive test for the binder showed that strength values increased when gypsum sludge content increased gradually. The 3-day old samples incorporated with 8% of gypsum waste had better strength compared to 7-day old samples. During the hydration process, gypsum waste could help in slowing down the loss of strength through the formation of ettringite. Therefore, the workability of the binder is very dependent on the tricalcium aluminate (C_3A) and calcium sulfate system ($CaSO_4$) [32]. After all, the samples were being tested and were proved for the ability to be reuse in fly ash brick.

Meanwhile, [33] conducted a study on the stabilization of adobe using gypsum waste. Adobe is recognized as one of the most established and most broadly used structure materials for decades. However, adobe has certain disadvantages including its high solubility in water. Thus, a stabilizer such as phosphogypsum or natural gypsum could help improve the performance of adobe. From the research, the stabilized adobe

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samples increased in strength when more gypsum waste was used. However, only a maximum of 25% of phosphogypsum could be added to adobe for stabilization purposes. Other than that, phosphogypsum also helps lengthen softening time, increase water resistance, reduce drying shrinkage and give a smooth appearance to the adobe samples.

On the other hand, fired clay brick is one of the building materials that is well known in the construction industry. Furthermore, recent decades have witnessed the increasing number of studies being done on using toxic waste as potential substitution in building materials. Brick is favored because of its locally available sources, ease of preparation, good features and adjustable composition. Meanwhile, the use of waste additives can help improve the properties of brick. The dangerous components in clay bricks will also undergo volatilization during the firing process. Under certain circumstances, the fixation of the materials will occur due to changes in the chemical and toxic content of recycled gypsum waste [34], [35]. The resulting fired clay bricks produced using gypsum waste would lead to ideal properties such as improved total shrinkage, low weight and high thermal conductivity. However, some properties such as porosity and water resistance might decrease due to the characteristics of gypsum waste. [22]. The quantity of waste that can be used in ceramic bodies and its effects on the end product will depend on the characteristics of the waste utilized. Endeavors by previous researchers in different types of toxic waste incorporation in building materials such as sludge, biodiesel, fly ash, sawdust and palm oil waste have shown several physical and mechanical improvements [36-42]. In addition, even though some deficiencies were present in the products, improvements such as lightweight bricks, lower density, fair compressive strength and lower consumption of energy during the manufacturing process were also observed. Table I shows a summary of studies on gypsum recycling.

Table I: Summary of studies on gypsumrecycling

Researcher	Gypsum recycling	Advantage
Zhu *et al.*, (2018)	Dihydrate gypsum block	Forming of crystals that increase strength values
Magdalena *et al.*, (2018),	Fire-resistant materials	Withstand high temperature
Bekele et al., 2015	Natural gypsum substitution	Decrease dependence on natural gypsum
Aly and Usama (2014)	Bind soil particles	Improve the strength of ground mixtures (gypsum and soil)
Kamei *et al.*, (2013), (2011); Ahmed &Ugai, (2011); Ahmed *et al.*, (2010b),	Soil stabilizer	Improve the stability and durability of soil
Nurhayat (2008)	Adobe stabilization	Increases strength, lengthens softening time, increases water resistance, reduces drying shrinkage and gives a smooth appearance to the adobe samples

Based on the studies conducted by many researchers, the successful results from the incorporation of toxic waste in fired clay bricks have encouraged the use of gypsum waste from wastewater treatment plants as replacement material in brick production. Thus, recycling gypsum waste not only helps solve waste disposal issues, but also the shortage of natural resources [41], [42].

IV. CONCLUSIONS

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The results of this study can be beneficial for chemical industries that produce waste containing high heavy metal content as it shows how gypsum waste can be generated. Due to mass quantities of gypsum waste generated, high management costs, stringent regulations and scarcity of landfill space, there is a crucial need to seek out appropriate methods for recycling gypsum waste. Based on the characteristics of gypsum such as the formation of crystals in dihydrate gypsum, fire resistance, facilitation in the recovery of byproducts, soil stabilizing properties and so on, it is feasible to recycle gypsum waste. However, an extensive study on the impacts of gypsum waste incorporated into building materials is needed to obtain the optimum percentages of gypsum waste which comply with the standards.

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V. REFERENCES

[1] Hayes, S. M., & McCullough, E. A. (2018). "*Critical minerals: A review of elemental trends in comprehensive criticality studies", Resources Policy*, *59*, 192-199.

[2] https://www.doe.gov.my/portalv1/en/industri/maklumat-untuk-industri/maklumat-umum-buangan-terjadual.

[3] Li, Y. C., Min., X. B., Chai, L. Y., Shi, M. Q., Tang. C.J., Wan, Q. W., & Liang, W. J. (2016), "Co-treatment of gypsum sxludge and Pb/Zn scmelting sclag for the solidification of sludge containing arsenic and heavy metals", in *Journal of environmental management*, 181, 756-761.

[4] Hao, Y., Li, Q., Pan, Y., Liu, Z., Wu, S., Xu, Y., &Qia, G. (2017), " *Heavy metals distribution characteristic of FGD samples from Shanxi Province 12 coal-fired power plant and its potential environmental impacts*", Fuel, 209 (May), 238-245.

[5] Lin, J., Sun, W., Desmarais, J., Chen, N., Feng, R., Zhang, P., Pan, Y. (2018). Uptake and Speciation of Uranium in Synthetic Gypsum (CaSO4 •2H2O): Applications to Radioactive Mine Tailings. Journal of Environmental Radioactivity, 181(October 2017), 8–17.

[6] Zoca, S. M., & Pen n, C. (2017). "*An Important Tool With No Instruction Manual: A Review of Gypsum Use in Agriculture",* Advances in Agronomy (1st ed., Vol. 144). Elsevier Inc.

[7] Department of Environment, Ministry of Energy, Science, Technology, Environment & Climate Change, Malaysia.

[8] Alvarez, E., Fernandez Marcos, M. L., Vaamonde, C., & Fernandez-Sanjurjo, M. J. (2003), "*Heavy metals in the dump of an abondoned mine in Galicia and in the spontaneously occurring vegetation*", Science of the Total Enviroment, 313 (1-3), 185-197.

[9] Murphy, A. P., Coudert, M., & Barker, J. (2000), "*Plants as B iomakers for monitoring heay metal contaminants on landfill sites using sequential extraction and inductively coupled plasma atomis emission spectrophotometry (ICP-AES)",* J. Environ.Monitoring., 2(6), 621-627.

[10] Planquart, P., Bonin, G., P. Rone, A., & Massiani, C. (1999), "*Distribution, movement and plant availability of trace metals in solids amended with sewage sludge composts*", 241 (1-3),161-179.

[11] Kadir, A. A., Sarani, N. A., & Leman, A. M. (2014), "*Testing on building material using waste material in fired clay brick*", Materials Science Forum, 803, 330-336.

[12] Prasad, M. N. V. (2016), "*Resource potential of natural and synthetic gypsm waste*", in M. N. V. Prasad & K. Shih (Eds.), Environmental Materials and Waste: Resource recovery and pollution prevention (pp. 1-728).

[13] Ukwatta, A., & Mojajerani, A. (2017), "*Characterisation on fired clay brick incorporating bio-solids and the effect of heating rate on properties of bricks*", Construction and Building Materials, 142, 11-22.

[14] C. Chandra, K. A. M. Azizli, Z. A. Ahmad, E. Sakai, "*Use of waste gypsum to replace natural gypsum as set retarders in portland cement*", Waste Management, 29 (2009), 1675-1679.

[15] Asakura, H. (2015), "*Sulfate and organic matter concentration in relation to hydrogen sulfide generation at inert solid waste landfill site limit value for gypsum*", Waste management, 43, 328-334.

[16] Lee, S., Xu, Q., Both, M., Townsend, T. G., Chadik, P., Bitton, G., (2006), "*Reduced sulfur compunds in gas from construction and demolition debris landfills*", Waste Management, 26, 526-533.

[17] Townsend, T., Jambec, J., Jang, Y., Plaza, C., Xu, Q., Clark, C., (2005), "*C&D Waste landfill in Florida: Assessment of true impact and exploration of innovative control techniques, Florida Cent. Solid Hazard*", Waste management., Gainesville, FL, USA.

[18] Inoue, Y., (2005), "*Mechanism of strong hydrogen sulfide gas formation in inert industrial waste landfill sites and countermeasures*", Res. Rep. Natl. Inst. Environment Stud. Japan, 188.

[19] De Beer, M., Mae, J. P., Lienberg, L., & Doucet, F. J. (2014), "*Conversion of calcium sulphide to calcium carbonate during the process of recovery of elemental sulphur from gypsum waste*", Waste Management, 34(11), 2373-2381.

[20] https://www.doe.gov.my/portalv1/en/info-laporan/laporan-jabatan-alam-sekitar/laporan-kualiti-alam-keliling/324265.

[21] Macias, F., Carabalo, M. A, & Nieto, J. M. (2012), "*Environmental asssssment and management of metal-rich wastes generated in acid mine drainage passive remediation systems*", Journal of Hazardous Materials, 229, 107-114.

[22] Bekele, T. A. (2015). Recycling Plaster of Paris from Discarded Gypsum M oulds for Tabor Ceramics Products Manufacturing Share Company. Addis Ababa University.

[23] Bhat, R. (2017). Sustainability Challen ges in the Agrofood Sector. Wiley.

[24] Lopez, C. M., Luis, J., Araiza, R., Manzano-ramire Z, A., Pineda, J., Landavede, M. A. H., De, A. M. (2011), "*Effect of fly ash and hemihydrate gypsum on the properties of unfired compressed clay bricks*", International Journal of the Physical and Sciences, 6(17), 5766-5773.

[25] Zak, P., Ashour, T., Korjenic, A., Korjenic, S., & Wu, (2016), "*The influence of natural reinforcement fibers, gypsum and cement on compressive strength of earth brick materials*", Construction and Building Materials, 106, 179-188.

[26] Zhu, C., Zhang, J., Yi, W., Cao, W., Peng, J., & Liu, J. (2018). Research on degradation mechanisms of recycled building gypsum. *Construction and Building Materials*, *173*, 540-549.

[27] Dolezelova, M., Scheinherrova, L., Krejsova, J., & Vimmrova, A. (2018). Effect of high temperatures on gypsum-based composites. *Construction and Building materials*, *168*, 82-90.

[28] Ahmed, A., & Issa, U. H. (2014), "*Stability of soft clay soil stabilised with recycled gypsum in wet environment*", Soils and Foundations, 54(3), 405-416.

[29] Ahmed, A., Ugai, K., & Kamei, T. (2011), "*Laboratory and field evaluations of recycled gypsum as a stabiliser agent in embankment construction*", Soils and Foundations, 51(6), 975-990.

[30] Ahmed, A., Ugai, K., & Kamei, T. (2012), "*Laboratory and field evaluations of gypsum as a stabilizer agent in embankment construction*", Soils and foundations, 51(6), 977-989.

[31] Ahmed, A., El Nagar, M. H., Ahmad, H. M., & Kamei, T. Recycling waste gypsum in soil stabilization applications.

[32] Minard, H., Garault, S., Regnaud, L., & Nonat, A. (2007), "*Mechanisms and parameters controlling the tricalcium aluminate reactivity*

January - February 2020
ISSN: 0193 - 4120 Page No. 11753 - 11760

in presence of gypsum", Cement and Concrete Research, 37(10), 1418-1426.

[33] Degimenci, N. (2008), "*The using of waste phosphogypsum and natural gypsum in adobe stabilization*", Construction and Building Materials, 22(6), 1220-1224.

[34] Kadir, A. A., & Mohajerani, A. (2015), "*Effect of heating rate on gas emissions and properties of fired clay brick and Fired clay bricks incorporated with cigarette butts*", Applied Clay Science, 104, 269-276.

[35] Ukwatta, A., Mohajerani, A., Eshtiaghi, N., & Setinge, S. (2016), "*Variation in physical and mechanical properties of fired clay bricks incorporating etp biosolids*", Journal of Cleaner Production, 119, 76-85.

[36] Aramide, F. O. (2012), "*Production and characterization of porous insulating fired bricks from ifon clay with varied sawdust admixtures*", Journal of Minerals and Materials Characterisation and Engineering, 11, 970-976.

[37] Cusido, J. A., Cemades, L. V., Soriano, C., & Devant, M. (2015), "*Incorporation of paper sludge in clay brick formulation: Ten years of industrial experience*", Applied Clay Science.

[38] Kadir. A. A., Sarani, N. A., Zaman, N. N., & Abdullah, M. M. A. B. (2017), "*Feasibility study on utilization of palm oil fibre waste into fired clay brick",* in Advanced Materials Engineering and Technology V. AIP Conf. Proc.

[39] Loutou, M., Hajjaji, M., Ait, M., Mansori, M., Favotto, C., & Hakkou, R. (2017). Phosphate sludge-based ceramics : Microstructure and e ff ects of processing factors. Journal of Building Engineering Journal,11(April), 48–55.

[40] Pimraksa, K., & Chindaprasirt, P. (2009). Lightweight Bricks Mad e of Diatomaceous Earth, Lime and Gypsum. Ceramics International, 35(1), 471–478.

[41] Raut, A. N., & Gomez, C. P. (2017), "*Development of thermally efficient fibre-based eco-friendly brick reusing locally available waste materials*", Construction and Building Materials, 133, 275-284.

[42] Ukwatta, A., & Mohajerani, A. (2017), "Effect of organic content in biosolid on the properties of fired clay bricks incorporated with biosolids", Journal of Materials in Civil Engineering, 29(7), 1-11).

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