

RESEARCH ARTICLE

A STUDY INTO THE PROPERTIES OF SANDCRETE BLOCKS PRODUCED FROM SPENT CATALYTIC CATALYST AS A PARTIAL SUBSTITUTE FOR PORTLAND CEMENT

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ABSTRACT

Spent Catalytic Catalyst (SCC) is a siliceous and aluminous material residue produced by the Tema Oil Refinery (TOR) Limited of Ghana, which pose environmental concerns. The SCC has therefore been used as a partial replacement for Portland cement in sandcrete blocks production. The properties of the sandcrete blocks are therefore examined and reported in this study. Partial replacement of Portland cement in the sandcrete blocks was done within the range of 5% to 20% (by mass) with an increment of 5%. The compressive strength, water absorption and setting time data between the control and with the SCC additives were made. The results obtained show that XRD pattern of SCC is dominantly zeolites and that, the partial replacement of portland cement with 10 wt. % of SCC gave the highest sandcrete block compressive strength of 34.0 N/mm².

KEYWORDS

Spent Catalytic Catalyst, Sandcrete, Portland Cement

1. INTRODUCTION

One of the most important basic needs of man is shelter, however close to 25% of the world's population lacks decent homes and particularly in African cities (González Mahecha et al., 2020). In this regard, it has been proven that most developing countries, particularly Ghana, will not be able to meet the growing demand of shelter without any established construction strategies for the utilization of low-cost construction materials (Osabutey et al., 2014). While shelter conditions in the last few decades have been worsening, resources have remained scarce and costs of building materials have escalated due to increase in population, and the urgency to provide immediate practical solutions has become more imperative (Afrane et al., 2016). Recent studies have reported that high cost of construction materials remains the most important cause of inadequate infrastructure. Principally, the predominant use of conventional materials (cement) continues to hinder the provision of shelter and other infrastructural facilities in Ghana and other developing countries (Awanyo et al., 2016).

In Ghana, the most widely used building material is sandcrete or concrete, which properties greatly depend on the properties and proportions of its constituents (Afrane et al., 2016). Portland cement is the major component of concrete or sandcrete blocks, the choice of its proper type and use has vital importance in obtaining the right balance of its desired properties in the most economical way. However, in spite of the introduction of advance technologies in the construction industry, the same industry is continuously saddled with defective building products. The preservation of quality and cost are essential factors in modern construction. The widespread reports in the media on structural defects and failures for both domestic and industrial structures point to a problem of poor construction materials usage in the industry. This phenomenon as pointed out by is

partly due to local contractors and masonry workers compromising the standard mixing ratios of construction materials such as the amount of Portland cement, which prices are at the mercy of economic factors (Acheampong et al., 2014).

Sandcrete belongs to a family of concretes, which can be used when environmental or economic constraints limit the use of coarse aggregate. Sandcrete products are made from coarse natural sand or crushed stone dust mixed with cement and water and pressed to shape. On setting and hardening, it attains sufficient strength to be used (BS 1992). In Ghana, sandcrete blocks are widely used as walling units and the properties of the blocks, specifically the quality differs from manufacturer to manufacturer due to the different methods employed in the production and the properties of the constituent materials. The high and continuously increasing cost of cement and its scarcity in Ghana have made it imperative to search for alternatives. This high cost is brought about by low production levels by local industry most often as price control gimmick, and particularly due to the high exchange rate of the local currency. In order to remain economical, in part, the solution to the high binder material cost could be in the form of obtaining local binder materials that can replace cement either partially or totally, but yet achieve the desired properties. Research into the use of alternative binding materials as a partial replacement of cement in concrete has shown very encouraging results with the discovery of spent catalyst of possessing some pozzolanic properties (Al-jabri et al., 2013a; Chen et al., 2004a; Soriano et al., 2013a).

Spent Catalytic Catalyst (SCC) is a residue from fluidized bed catalytic rupture units of the petroleum industry. This residue consists mainly of an active component (Y-zeolite - faujasite type) in an amorphous aluminosilicate matrix (Rodríguez et al., 2013). Its chemical composition is basically silica and alumina in percentages of up to 90%. The particle

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diameter of ground FCC residue is 19.73 μm , and almost the same as Portland cement (19.2 μm) (Soriano et al., 2013). Several researchers have reported amounts of spent catalyst generated, which is in range of millions of tons per year (Singh, 2009a). Moreover, there have been environmental concerns about the hazardous nature of this material, as it has been classified among materials of hazardous industrial waste, hence the need to find an alternative use for it as a means of safe disposal (Singh, 2009b).

As a material possessing an excellent pozzolanic properties, it has been reported to be used as a partial replacement for Portland cement for the manufacture of hydraulic binders. Given the high reactivity of Spent Catalytic Catalyst (SCC), it has been reported that the optimum replacement of Portland cement by this material ranges about 15-20%. This is because with higher percentages of replacement, part of the catalyst acts as an inert material, for having no calcium hydroxide, which is generated by cement hydration, available for the pozzolanic reaction (Al-jabri et al., 2013b). This residue has proven to behave as an excellent pozzolan for early curing age, improve both durability and mechanical properties of the cementitious matrices that contain it. It is used as a substitute of bauxite in the preparation of cement clinker Portland. SCC has been evaluated for use in road construction as a whole replacement for crushed aggregates in the sub-base and base layers and as a partial replacement for Portland cement in masonry blocks manufacturing (Soriano et al., 2013b).

It is against this background that this work is identifying additional materials which bring both environmental and financial benefits such as the substitution of a portion of cement which is able to comply with standard construction materials and its performance target as well, reduction in the cost of production of clinker and greenhouse gas emissions particularly CO_2 and to add value to the Spent Catalytic Catalyst (SCC) obtained from Residue Catalytic Cracking Unit of Tema Oil Refinery (TOR) Limited of Ghana, which when not used, would have to be properly and environmentally disposed. Thus, the main objective is to assess the behavior of the pastes and mortars of Portland cement partially replaced by SCC – at different temperatures and curing times to evaluate their behavior under such severe conditions.

2. MATERIALS AND METHODS

2.1 Materials

Spent Catalytic Catalyst (SCC) in this study was obtained from the Tema Oil Refinery (TOR) Limited located in the city of Tema, Ghana. Sand was sourced locally and sieved to meet specified requirements for sandcrete blocks by passing it through 850 μm (No.20) as in which was clean and free from all deleterious matter (BS 1992). Table 1 shows the physical properties of the normal Portland cement and the spent catalytic catalyst that were determined according to ASTM standards requirement (ASTM C204).

Table 1: Physical Properties Portland Ghacem Cement and SCC				
Property	Quantity		ASTM Method	Value
	Ghacem Potland Cement	SCC		
Specific Surface (m^2/kg)	370	90	C 204	381.8 m^2/kg $\pm 7.8 \text{ m}^2/\text{kg}$
Specific Gravity (g/cm^3)	3.15	2.9	C 204	3.15

2.2 Method: Experimental Procedure

The technique adopted to collect data was by direct observation of the processes involved in the preparation of sandcrete cubes from the selected samples. Some parameters or conditions observed at the cube preparation stages were the general temperature conditions under which the cubes were being prepared, the measuring of the cement and Spent Catalyst samples, storage temperature, that is ambient temperature (298.15K), pressure (100kPa), mixing procedures, sandcrete preparation for vibration, curing procedures and lastly the crushing process. Other investigations conducted on sample included the Setting Time Test, Chemical Test and the Test for distilled water. Cement test as already described in the standard has to follow particular procedures. These procedures are shown in Figure .

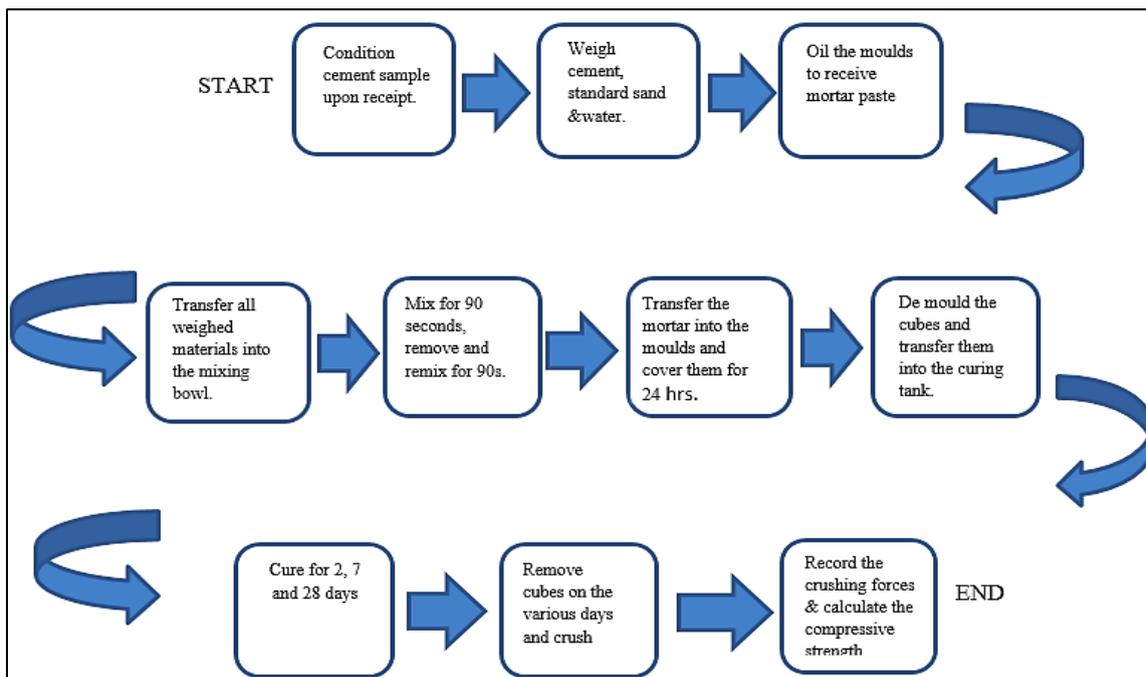


Figure 1: Flow chart depicting the experimental procedure

2.3 Mixture Production of Sandcrete Blocks

Sandcrete blocks were prepared from Ghacem 32.5R cement (600 g),

standard quartz-sand (1800 g) and tap water (300 mls); the ratios of mixture of the starting materials are shown in Table 2.

Table 2: Proportion of Materials in Sandcrete Mixture					
Sample ID	Samples	Cement (g)	Spent Catalytic Catalyst (g)	Sand (g)	Water(ml)
S _c	Control	600	0	1800	300
S _{5%,95%}	5% SCC, 95% cement	570	30	1800	300
S _{10%,90%}	10% SCC, 90% cement	540	60	1800	300
S _{15%,85%}	15% SCC, 85% cement	510	90	1800	300
S _{20%,80%}	20% SCC, 80% cement	480	120	1800	300

In the production of the test sample sandcrete blocks, part of the cement is replaced with 5 to 20% mass of Spent Catalytic Catalyst. A total of 45 sandcrete cubes blocks measuring 70 mm x 70mm x 70mm sandcrete moulds were prepared, cast and cured at 2 days, 7 days and 28 days (Figure).



Figure 2: Samples of Sandcrete Blocks (cubes) produced and labelled for crushing

The sample sandcrete blocks were prepared by mechanically mixing and compacting the mixture into a mould using a Jolting Apparatus. The samples were labelled (Figure) immediately after moulding and left in the mould within a moist atmosphere for 24 hours. Samples were removed from the water 15 minutes before each test was due. These samples were then demoulded and placed in tap water for curing at a temperature of 20 ± 1.0 °C until they were due for testing.

2.4 Compressive Testing

The samples were subjected to stress using the Compressive Test Machine increasing the load progressively. The load increase was regulated by hand, care was taken when adjustments were made for the decrease of the loading rate near fracture load as this could affect the results.

2.5 Setting Time Test

The filled mould and base plate were placed in a container filled with water at a controlled temperature of 20 ± 1 °C. After a period of time the sample was removed and placed under the Vicat and the needle dropped gently onto the paste. The scale was read when penetration had ceased or 30 seconds after the release of the needle. The scale readings, which indicated the distance between the needle and the base plate, were recorded. The penetration was repeated on the same sample until the time where the distance between the needle and the base plate was 6 ± 3 mm measured to the nearest minute. This is the Initial Setting time of the cement or Spent Catalytic Catalyst and is reported to the nearest 5 minutes. In the determination of the final setting time, the paste in mould used for the initial setting time was inverted and again immersed under water. This time the needle was dropped until a reading of 0.5 mm was recorded. This indicates the final setting time has been achieved.

2.6 Standard Consistence Test

The manual Vicat Apparatus with a plunger was used to weigh a total of 300 ± 1 g. The movement of the Vicat Apparatus with plunger was kept truly vertical. The mould to contain the paste is made of rubber or brass placed on glass flat base. In mixing the cement paste, weigh to an accuracy of ± 1 g by means of the balance, 500g of cement or Spent Catalytic Catalyst and a quantity of water e.g., 125g. The weighed items were mixed using the mixer at low speed. The paste produced was immediately transferred into a lightly oiled mould; any voids were removed in the paste by gently tapping the sides of the mould and levelling to the top surface.

Immediately after levelling the paste, it was transferred onto the Vicat Apparatus and the plunger dropped intermittently. This was repeated until the distance between the plunger and paste was 6 ± 2 mm.

3. RESULTS AND DISCUSSION

3.1 X-ray Diffraction (XRD)

Two crystalline zeolite phases were identified from the XRD pattern plot shown in Figure . The XRD pattern plot indicate that, the Spent Catalytic Catalyst are primarily composed of dehydrated dealuminated Y-zeolite ($H_{149.12}O_{458.56}Si_{192}$) and A-zeolite ($Al_{12}Ca_{5.13}Cs_{1.74}O_{48}Si_{12}$).

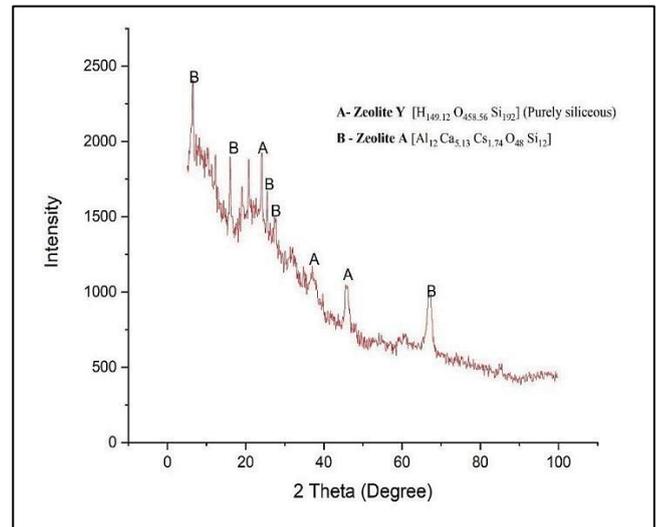


Figure 3: XRD Patterns of Spent Catalytic Catalyst from Tema Oil Refinery

In addition, it is observed that, there is a possible presence of high amounts of amorphous phases resulting from partial destruction of the zeolite crystal structures during catalyst synthesis or regeneration process (Rodríguez et al., 2013). A group researchers concluded that zeolite-based spent catalytic catalysts are effective precursor for the production of geopolymer binders (Rodríguez et al., 2013).

3.2 Effect of Spent Catalytic Catalyst on Compressive Strength

The compressive strength values of the standard blocks presented in were computed using equation 1. The Figure shows the relationship between the average compressive strength (f_c) of the blocks produced under and days of curing (BS, 1983).

$$f_c = \frac{P}{A} \quad (1)$$

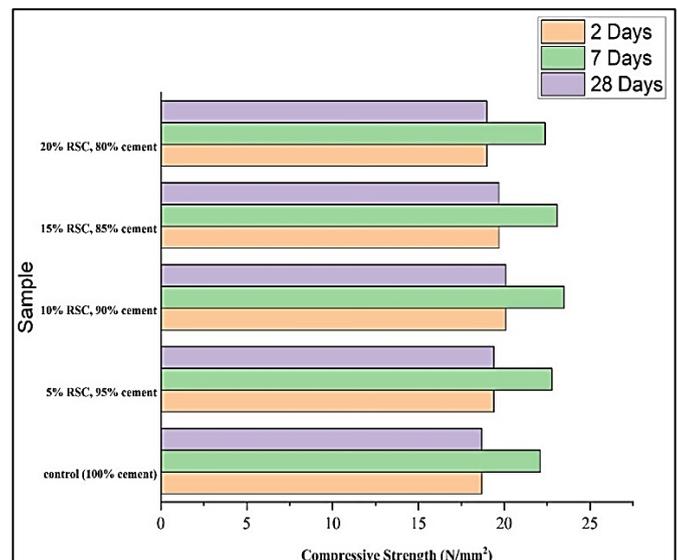


Figure 1: Relationship between compressive strength of replaced Portland Cement with Spent Catalytic Catalyst in sandcrete blocks for various samples for 2, 7 and 28-days curing period

The results indicated that increasing the amount of spent catalyst in mortar resulted in increased in the compressive strength of the blocks as shown in Figure 2. Comparison of the data for 2,7 and 28 days of curing period shows that the compressive strength achieved maximum strength for each curing days is achieved at 10% Spent Catalytic Catalyst and 90% Portland cement that was used for the sandcrete blocks moulding. Moreover, the 28 days curing time achieved the highest compressive strength results of $34N/mm^2$ in this study.

The Spent Catalytic Catalyst (SCC) activity is due to its ability to react with the calcium hydroxide (portlandite) released in the hydration of Portland cement and form compounds with hydraulic properties. This behavior causes additional increase in the mechanical strength of sandcrete

(Borrachero et al., 2002). Also, the high specific area of Spent Catalytic Catalyst (SCC) (mean particle diameter been 19.73 μm) led to a number of nucleation sites for additional hydration products, this possibly increased the hydration heat all over the period of testing (Marafi and Stanislaus, 2008). The hydration heat increase is attributed to a possible pozzolanic activity, SCC which possesses pozzolanic property; high in siliceous and aluminous content (Table) (ability of binding with $\text{Ca}(\text{OH})_2$) reacts to release hydration heat energy (exothermic effect) in the Portland sandcrete (Chen et al., 2004; Kubissa et al., 1998).

Properties	Portland Ghacem Cement	(SCC)	ASTM (C150)
(wt. %)			
Al_2O_3	6.9	48.5	7.56
Fe_2O_3	3	0.54	6
CaO	63	1.01	68
SiO_2	21.9	23.7	24.5
MgO	2.5		6
SO_3	1.7		4
Carbon		0.04	

Owing to which the cement paste sets much more rapidly increasing the hydration heat due to the exothermic effect of the pozzolanic reaction, thereby resulting in relatively higher Compressive Strength or mechanical strength of the sandcrete block. Additionally, the possibility of the formation of secondary calcium silicate/aluminate hydrate as confirmed from the high content of Si and Al (48.5 wt. %) was the major contributing factor to the higher strength performance of the SCC replaced sandcrete block than the control.

3.3 Effect of Spent Catalytic Catalyst on Setting Time

From Figure it can be seen that the initial setting time measured for sandcrete with Spent Catalytic Catalyst (SCC) was found to be lower than that of the control; also, the final setting time measured for control was higher than the sandcrete with SCC.

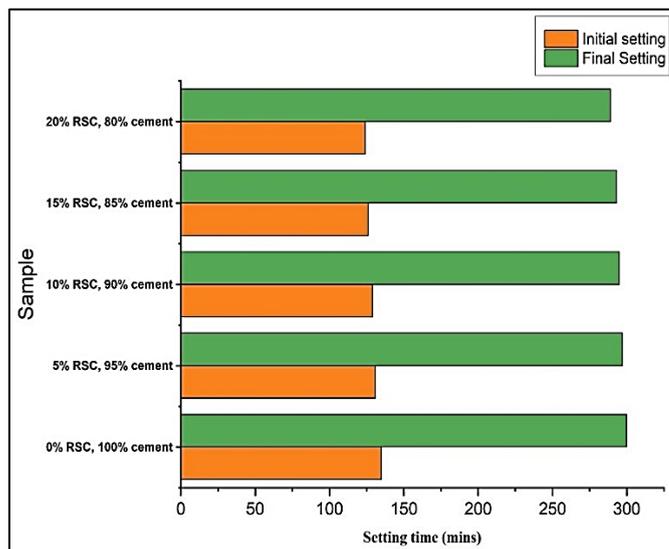


Figure 5: Setting Time Plots for Replaced Portland Cement with Spent Catalytic Catalyst in Sandcrete Blocks

This phenomenon can be attributed to the increase in the hydration heat resulting from the replacement of the cement with SCC. The sandcrete blocks with SCC solidifies and hardens faster through this chemical process called hydration thereby reducing the setting time. From above, it is observed that as the Compressive Strength increased to maximum strength at 10% SCC replacement, the setting time decrease throughout the specified period (Figure). This observation supports as referenced in the article that the optimum replacement of Portland cement with Spent Catalytic is about 15-20% with 10% replacement possible without any adverse effect to the Compressive Strength of the material (Al-jabri et al., 2013). This can possibly be attributed to the fact that increases in the SCC replacement content in the cement increased the hydration heat resulting in increased compressive strength thereby reducing the setting time.

3.4 Effect of Spent Catalytic Catalyst on Water Absorption and Compressive Strength

From Figure , it could be observed that the water absorption for the sandcrete with SCC was found to be lower compared to control sandcrete. This phenomenon is as a result of the molecules of water in the hydrated form in zeolites of the SCC, when the SCC addition was incorporated in the sandcrete and also due to increased hydration heat resulting in reduced amount of water retained (Ratio et al., 2019).

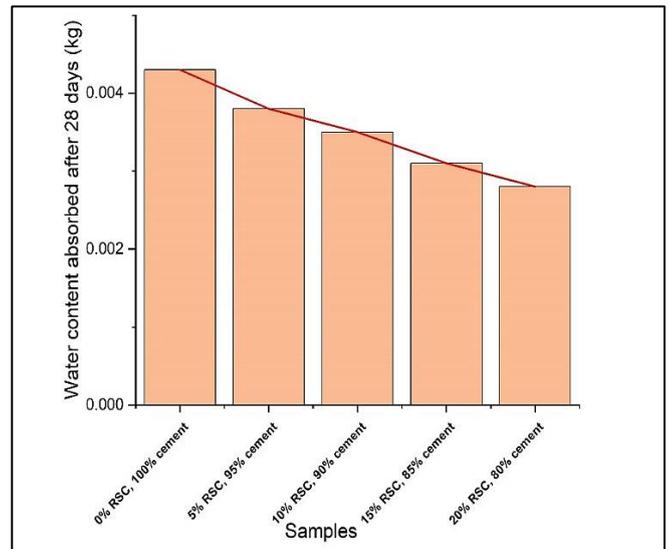


Figure 6: Water Absorption curve for various samples after 28 days curing

A group researchers indicated that, spent catalyst modifies the course of the hydration process (Pacewska et al., 2000). As a pozzolan additive, its presence leads to a decrease in calcium hydroxide contents in the system. The spent catalyst thus affects the heat of cement hydration ultimately decreasing the water content. Thus, small amounts additive of the SCC accelerates the process of binding.

4. CONCLUSION

Spent Catalytic Catalyst generated by the Tema Oil Refinery has proven to have beneficial applications in cement replacement for the production of sandcrete blocks due to their chemical compositions (Zeolites). For cement replacement of ratio 10% SCC and 90% Portland cement ($S_{10\%, 90\%}$), the results do not suggest significant increase in the compressive strength of the sandcrete blocks for various days of curing. However, a substitution ratio of 10% of SCC and cured for 28 days resulted in a higher compressive strength than the control mixture. Encouraging results were obtained of the mixtures prepared from the Spent Catalytic Catalyst and thus can be used safely without compromising the engineering properties of the sandcrete blocks and by extension the infrastructure that will it be used to construct. The results show that, spent catalytic catalyst can be safely used to partially replace Portland cement in sandcrete mixtures without compromising on the properties and quality. Also, the partial replacement of the spent catalyst has the potential of reducing construction cost and also efficiently managing hazardous waste generation in the environment.

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REFERENCES

- Acheampong, A.D.A.R.R.I., Hackman, A., Ayarkwa, J., Agyekum, J., 2014. Factors Inhibiting the Use of Indigenous Building Materials (IBM) in the Ghanaian Construction Industry. Africa development and resources research institute (adrri) journal adrri journals (www.adrri.org) 8, Pp. 2343-6662.
- Afrane, E., Bujang, A.A., Bin, Liman, H.S., Kasim, I., 2016. Major Factors Causing Housing Deficit in Ghana. Developing Country Studies, 6, Pp. 139-147.

- Al-jabri, K., Baawain, M., Taha, R., Al-kamyani, Z.S., Al-shamsi, K., 2013a. Potential use of FCC spent catalyst as partial replacement of cement or sand in cement mortars. *Construction and Building Materials*, 39, Pp. 77–81. <https://doi.org/10.1016/j.conbuildmat.2012.05.035>
- Al-jabri, K., Baawain, M., Taha, R., Al-kamyani, Z.S., Al-shamsi, K., 2013b. Potential use of FCC spent catalyst as partial replacement of cement or sand in cement mortars. *Construction and Building Materials*, 39, Pp. 77–81. <https://doi.org/10.1016/j.conbuildmat.2012.05.035>
- Awanyo, L., McCarron, M., Morgan, Attua, E., 2016. Affordable housing options for all in a context of developing capitalism: Can housing transformations play a role in the Greater Accra Region, Ghana? *African Geographical Review*, 35, Pp. 35–52. <https://doi.org/10.1080/19376812.2014.943774>
- Chen, H.L., Tseng, Y.S., Hsu, K.C., 2004a. Spent FCC catalyst as a pozzolanic material for high-performance mortars. *Cement and Concrete Composites*, 26, Pp. 657–664. [https://doi.org/10.1016/S0958-9465\(03\)00048-9](https://doi.org/10.1016/S0958-9465(03)00048-9)
- Chen, H.L., Tseng, Y.S., Hsu, K.C., 2004b. Spent FCC catalyst as a pozzolanic material for high-performance mortars. *Cement and Concrete Composites*, 26, Pp. 657–664. [https://doi.org/10.1016/S0958-9465\(03\)00048-9](https://doi.org/10.1016/S0958-9465(03)00048-9)
- González, M.R.E., Rosse, C.L., Garaffa, R., Lucena, A.F.P., Szklo, A., Toledo, F.R.D., 2020. Constructive systems for social housing deployment in developing countries: A case study using dynamic life cycle carbon assessment and cost analysis in Brazil. *Energy and Buildings*, Pp. 227. <https://doi.org/10.1016/j.enbuild.2020.110395>
- Kubissa, J., Pacewska, B., Wilin, I., 1998. Use of spent catalyst from catalytic cracking in fluidized bed as a new concrete additive, 322, Pp. 175–181.
- Marafi, M., Stanislaus, A., 2008. Spent catalyst waste management: A review. Part I-Developments in hydroprocessing catalyst waste reduction and use. *Resources, Conservation and Recycling*, 52, Pp. 859–873. <https://doi.org/10.1016/j.resconrec.2008.02.004>
- Osabutey, E.L.C., Williams, K., Debrah, Y.A., 2014. The potential for technology and knowledge transfers between foreign and local firms: A study of the construction industry in Ghana. *Journal of World Business*, 49, Pp. 560–571. <https://doi.org/10.1016/j.jwb.2013.12.009>
- Pacewska, B., Wilińska, I., Bukowska, M., 2000. Hydration of cement slurry in the presence of spent cracking catalyst. *Journal of Thermal Analysis and Calorimetry*, 60, Pp. 71–78.
- Perraki, T., 2003. The effect of natural zeolites on the early hydration of Portland cement, 61, Pp. 205–212. [https://doi.org/10.1016/S1387-1811\(03\)00369-X](https://doi.org/10.1016/S1387-1811(03)00369-X)
- Ratio, S., Al, Liguori, B., Aprea, P., Gennaro, B., De, Iucolano, F., Colella, A., Caputo, D., 2019. Pozzolanic Activity of Zeolites: The Role of Si/Al Ratio. materials.
- Rodríguez, E.D., Bernal, S.A., Provis, J.L., Gehman, J.D., Monzó, J.M., Payá, J., Borrachero, M.V., 2013. Geopolymers based on spent catalyst residue from a fluid catalytic cracking (FCC) process. *Fuel*, 109, Pp. 493–502. <https://doi.org/10.1016/j.fuel.2013.02.053>
- Singh, B., 2009a. Treatment of spent catalyst from the nitrogenous fertilizer industry-A review of the available methods of regeneration, recovery and disposal. *Journal of Hazardous Materials*. <https://doi.org/10.1016/j.jhazmat.2009.01.071>
- Singh, B., 2009b. Treatment of spent catalyst from the nitrogenous fertilizer industry-A review of the available methods of regeneration, recovery and disposal. *Journal of Hazardous Materials*. <https://doi.org/10.1016/j.jhazmat.2009.01.071>
- Soriano, L., Monzó, J., Bonilla, M., Tashima, M.M., Payá, J., Borrachero, M.V., 2013a. Cement & Concrete Composites Effect of pozzolans on the hydration process of Portland cement cured at low temperatures. *Cement and Concrete Composites*, 42, Pp. 41–48. <https://doi.org/10.1016/j.cemconcomp.2013.05.007>
- Soriano, L., Monzó, J., Bonilla, M., Tashima, M.M., Payá, J., Borrachero, M.V., 2013b. Cement & Concrete Composites Effect of pozzolans on the hydration process of Portland cement cured at low temperatures. *Cement and Concrete Composites*, 42, Pp. 41–48. <https://doi.org/10.1016/j.cemconcomp.2013.05.007>

