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The Use of Industrial Wastes as Filler in Concrete/Mortar: A Critical Review

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Abstract: This study presents a review on use of industrial waste in concrete or mortar to understand their individual effect when used as filler and the filler effect when used either as replacement of fine aggregate or cement. Materials like limestone dust, ground quartz, carbon black and marble dust sewage sludge are reviewed. Filler plays a significant role in concrete not only contributing to strength improvement and other properties in concrete but also as a replacement of fine aggregate or cement, especially when waste materials are use. This process will help eliminate environmental hazards and minimize the excessive consumption of conventional materials like fine aggregate and cement where the sources are becoming scarce and expensive. However, it was observed from the reviewed literature that in replacement level of some of this materials as filler with respect to the percentage that will contribute towards improving the properties of the concrete, the replacement should be typically below 30% for a sustainable concrete. As the particle size of the filler has an effect on the performance of the concrete or mortar, it is also observed that the suitable particle size range of the filler was below 65 μm for optimum result whereby reducing the total porosity of the concrete and mortar.

Key words: Filler effect, filler, limestone dust, ground quartz, carbon black, marble dust, sewage sludge ash

INTRODUCTION

As the demand for construction increases, so does the demand and cost of materials to be utilised in various construction work increases, concrete is one of the oldest construction material which is still the reliable material used in construction industry. Due to limited supply of most materials that are used in concrete work, researchers are now focusing on replacing most of the constituent material that make-up concrete which will reduce cost and still maintain a standard quality of the said concrete. Due to this fact attention is now being drawn into finding new sources of raw materials for concrete. This has led to more research been done on utilizing most industrial by-product as filler in concrete which in most cases are used to replace fine aggregate or cement (as filler or substitute to cement).

Fillers are material used in concrete to fill gaps between aggregates and lower consumption of binders and improve the properties of the mixed materials, when they are mixed with cement, they help improve the particle packing and above all create other properties in fresh concrete. According to European Standard EN 13139 (2002) fillers are fine materials that pass through 0.063 mm sieve size, Cordeiro *et al*. (2008) described filler as the packing characteristics of a chemically inactive material of a mixture that depends on shape texture and particle size distribution of the said material. Moreover, little pores present within particles in concrete or cement paste can be filled by a finer particle (filler) and this effect will significantly affect the properties of the cement pastes and the concrete giving rise to a more improved concrete structure (De Schutter, 2011).

In summary fillers are utilized in other to enhance the granular filling factor and luck-up capillary pores in a concrete mix (Bonavetti, 1998; Soroka and Setter, 1977), these fillers can either be reactive (pozzolanic) or nonreactive materials. Numerous studies have been done both past and ongoing using different by products (rice husk ash, palm oil fuel ash, olive oil ash sugarcane and bagasse ash, fly ash, silica fume, limestone, ground river sand, quartz, metakaolin and mable dust) as filler in replacement of fine aggregate or cement in other to have a clear understanding of the effect of this by-products. Most especially, when a reactive by-product is introduced, it is important to understand its fundamental effect (to identify both filler effect and pozzolanic effect, to know the specific effect of the material) when used in concrete or other construction purpose (Karim *et al*., 2013; Zain *et al*., 2011; Shukla *et al*., 2011; Cheerarot *et al*, 2004; Rashad *et al*., 2014; Khan *et al*., 2017; De Schutter, 2011; Oey *et al*., 2013). Several research have incorporated nonreactive filler with reactive filler to distinguish between filler effect and pozzolanic effect

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(Jaturapitakkul *et al.*, 2011; Khan *et al.*, 2014, 2017), this indicates that pozzolanic materials when used as replacement of either fine aggregate or cement in concrete or mortar gives two effects; they act as filler to fill the internal voids and as pozzolanic material to improve strength of the concrete or mortar by reacting with the cement. This review present research on different filler material like limestone dust, ground quartz, carbon black, marble dust and sewage sludge ash and their effect on mortar and concrete properties, it is thus important to note that most filler materials possess both filler effect and pozzolanic effect while others have little or no reaction to cement hydration (non-reactive).

TYPES OF INDUSTRIAL WASTE AS FILLER

Several industrial by-products have been used in the past as filler in concrete and mortar to investigate the filler effect of pozzolanic material which have added knowledge on filler effect in some cementations materials in terms of differentiating filler effect and pozzolanic effect. Filler which its main attribute is to fill the internal particle voids between aggregates due to its particle sizes (Zhang *et al.*, 1996; Cardeiro *et al.*, 2011) and in some cases improve the walkability of the fresh concrete and increase the strength of the concrete. Some of this industrial by-product (non-reactive) used as filler will be reviewed in this study.

Ground quartz: Quarts have been used in the past research in establishing filler effect with different filler material most especially, pozzolanic materials, quartz is seen more as a nonreactive material having a very high content of Silicon Dioxide (SiO_2).

Several attempt in the past have been made to incorporate this material with other pozzolanic material to better understand the filler effect when those pozzolans are used to replace fine aggregate or cement. Moosberg-Bustnes *et al.* (2004) studied the effect of quartz as filler and the possibility of replacing cement with quartz in different particle size and different amount of replacement. The researchers reported that quartz as filler showed a positive effect by improving particle parking, thus, filling the voids. They further explained that the particle fineness also had effect in improving the hydration of the concrete (Table 1).

The result of Moosberg-Bustnes *et al.* (2004) was similar to the result from experimental investigation done by Kronlof (1994) who used quartz powder with the intention of improving "Particle parking" in workability of concrete. The result showed that the finest particle of the filler improved the filling effect (filler effect) therefore, reduce the water content, improve workability, reducing demand for binder and also increased the strength of the concrete due to the interaction between the paste and the aggregate with reduced porosity.

In an experimental study by Cordeiro *et al.* (2008) to investigate the filler effect of quartz with the particle size of crushed quartz of 29.1 μm. They found that the crushed quartz assisted in gaining early strength due to the filler effect. This implies that the effect of filler is substantial in early stage strength development and this prove was clear when compared to the control sample. Berodier and Scrivener (2014) carried investigation on filler effect with the aim to study the effect of filler and kinetic hydration when quartz in different percentage cement replacement 10, 20, 40, 50 and 70%. They reported that although, quartz is inert as stated it also enhances the rate of reaction of the clinker. It was also observed that in every replacement level there was relationship of increasing acceleration slope which is attributed to the particle size and replacement level of the quartz.

Carbon black: Carbon black is a by-product generated from rubber industry and is considered as an inert material (nonreactive material) which is also a good material to help understand the filler effect of some pozzolanic material. It can be seen in spherical shapes and a very small size particles (powder) that are similar to silica fume, attempt has been made in the past to clear the difference between pozzolanic effect and filler effect when the material is used in concrete. Carbon black has been used in different studies in the past as filler material and substitute to cement in concrete. Goodman and Bentur (1993) used different particle sizes of carbon black (mean

Table 1: Compressive strength of concrete with quartz as filler (Moosberg-Bustnes *et al.*, 2004)

	216 kg cement	w/c = 0.96	260 kg cement	w/c = 0.81	260 kg cement	w/c = 0.96
Filler (kg)	7 days (MPa)	28 days (MPa)	7 days (MPa)	28 days (MPa)	7 days (MPa)	28 days (MPa)
216	-		24.4	32.6	16.5	17.3
260	12.0	17.7	24.6	33.0	19.5	20.9
300	15.5	21.9	24.3	32.3	19.8	21.2
343	16.8	23.1	27.0	36.4	21.2	22.2
386	17.5	24.2	28.9	38.0	20.5	22.1
433	18.9	26.6	-	-	-	-

particle sizes 0.025, 0.073 and 0.33 μm) to study the influence of micro-filler of concrete in strength enhancement. A cube of size 70×70×70 mm and beam size 70×70×280 mm was used to prepare concrete while the pastes matrix was prepared with a 25×25×25 mm mould. The findings indicate that the addition of carbon black influence the strength of the concrete practically similar to the silica fume of the same water cement ratio 0.46. The strength increase was due to decrease in particle fineness (particle size smaller than 0.073 μm) and due to "Densification of the transition zone" which showed that a finer particle improves the micro-filler effect in the concrete whereby enhances the strength by filling the voids in the concrete.

Padma and Pandeeswari (2016) utilized carbon black as filler in different percentages 10, 20 and 30% to study the effect of carbon black in concrete partially replacing cement. The researcher found that the strength of the concrete increased with increase in carbon black content at 30% and this mix had the best strength among the other mix in their study including the reference concrete cube. This increase is attributed to the filler effect of the carbon black in the concrete mix which led to a conclusion that replacement of cement with carbon black up to 30% was ideal and would be significant. Chitra *et al.* (2014) added carbon black powder in different percentages (0, 2, 5, 8, 12 and 15) as filler in conventional concrete. The researchers concluded that 2 and 5% of carbon black gave better compressive strength when compared to the control concrete but in terms of the morphology 8% carbon black had a better filling effect in the concrete whereby closing the internal voids between the particles present in the concrete but went ahead to advise that 5% of carbon black as filler will be an ideal percentage addition of carbon black in concrete to enhance the performance of the concrete having percentage increase of strength at about 27.73% when compared with the reference sample (Table 2).

A similar percentage addition of carbon black was later used by Jeyashree and Chitra. (2017) who explored the effect on a concrete element with carbon black powder as filler material having a particle size of 0.05 μm with different percentage replacement of 0, 2, 5, 8, 10 and 12%. The result from this study as certained that 2, 5 and 8% carbon black to optimum cement replacement had the best result when compared to the control sample in terms of compressive strength, rebound hammer test and ultrasonic pulse velocity test which indicates that carbon black is a good ingredient as filler material in concrete to improve the properties of concrete structure for Reinforced Cement Concrete (RCC) elements. This was due to the particle size of the carbon black which reduced the internal void present in the concrete.

Table 2: Compressive strength of concrete with carbon black as filler (Chitra *et al.*, 2014)

Replacement content with carbon black (%)	Compressive strength (n/mm^2)	Increase in compressive strength (%)
0	24.30	-
2	28.44	+17.03
5	29.33	+20.7
8	17.56	-27.73
12	13.33	-45.14
15	11.56	-52.42

Table 3: Chemical composition of marble dust

	Composition (%)	
Chemicals	Aruntas *et al.* (2010)	Bekir (2009)
SiO_2	0.67	4.67
Na_2O	0.14	-
MgO	0.59	0.4
Fe_2O,	0.08	0.03
Al_2O_3	0.12	-
CaO	54.43	51.8
LOI	43.40	41.16

Marble dust: Marble dust is a by-product generated during the process of cutting marbles, it consists of high CaO up to 50% and other minor chemical content of SiO_2, Na_2O, Mg_2, Fe_2O, Al_2O_3 (Southararajan and Sivakumar, 2013). The chemical composition differ from sample to sample due to the formation of the parent marble rock from origin as shown in Table 3.

This by product has been used in the past studies and has performed very well as filler in concrete when used as a substitute to fine aggregate or replacing cement in specific percentage as filler material. An experimenter study done by Almeida *et al.* (2007) when marble slurry was used as substitute for sand in different percentages 5, 10, 15, 20, 34, 67 and 100, the result showed strength increase at early age with percentage increase of 10.3 of compressive strength at 7 days and at 28 days 7.1% increase when compared to the reference sample. The observed increase was due to the fact that the marble slurry acted as micro filler, filling the internal pores between the aggregates. It was also detected from the result that 5% sand substitution yield the best strength in terms of compressive strength, splitting tensile strength and modulus of elasticity. Hamza *et al.* (2011) used marble waste to replace fine aggregate up to 40% to test the physical and mechanical properties of concrete brick according to ASTM standard and Egyptian code. The study proved that the concrete brick with marble waste fulfilled both standards with respect to the physical and mechanical properties of the sample whereas the sample without the marble waste had a low strength because the mix had a poor filling particle and poor grain size distribution.

Topcu *et al.* (2009) reported on self-compacting concrete using marble dust as filler and replacing cement with marble dust in different content 50, 100, 150, 200, 250 and 300 kg/m³ to study the effect of marble dust as filler in self-compacting concrete. The experimental study showed that 200 kg/m³ is the best dosage for marble dust as filler in self-compacting concrete and that marble dust had a positive effect on the concrete in both fresh and hardened state of the concrete, giving rise to increasing of strength in early and later age of the concrete sample which was due to filler effect of the marble dust that filled up the gaps between the particles in the mix. They specified that the addition of marble dust above 200 kg/m³ would bring about decrease in mechanical properties of hardened self-compacting concrete. Meanwhile, Hameed *et al.* (2016) studied effect of marble dust in self-compacting concrete as filler by using marble dust to replace cement in different content 5, 10, 15 and 20 by weight. In view to that the result showed that the use of marble dust (marble powder) to replace cement contributed to strength of the self-compacting concrete by acting as effective filler with a size particle finer than 150 μm. They found that 15% of marble dust content replacing cement gave a more suitable result without a reduction in the strength and other properties of the self-compacting concrete.

Demirel (2010) carried out an experimental study using waste marble dust as a fine aggregate on mechanical properties of concrete, having four different concrete mix with different percentages 25, 50 and 100 replacement and curing age 3, 7, 28 and 90 days. The result shows that addition of marble dust as replacement of fine aggregate of particle size passing through 0.25 mm sieve size improved the strength of the concrete and the unit weight because of the fineness particles of the marble dust and the higher specific gravity which gave a filler effect in the concrete structure due to the fact that marble dust particle size was finer than that of the fine aggregate in their study (Table 4).

Corinaldesi *et al.* (2010) highlighted that marble dust shows filler effect at early age because of filler potentials of the marble dust and does not contribute chemically to the hydration process of the cement which means that marble powder is inert. The researcher also reported an increase in compressive strength at 28 days of age when marble dust replaced fine sand up to 10% more than the control concrete, giving an improved and promising concrete and mortar behaviour. Chandra *et al.* (2002) conducted a study using marble dust as filler in bituminous concrete with different replacement content 3, 5, 7 and 9%. The result showed that 5% marble dust filler content had the best strength among other filler in the study. This showed that the utilization of this by-product as filler in concrete will yield a successful and sustainable material for construction.

Table 4: Compressive strength of concrete with Marble dust as filler (Demirel, 2010)

	Compressive strength (MPa)			
Replacement (%)	3 days	7 days	28 days	90 days
0	14.32	35.50	48.68	60.51
25	15.80	35.54	50.25	61.44
50	17.66	36.43	50.69	61.50
100	21.46	38.97	53.39	63.30

Table 5: Physical and chemical composition of limestone (Isaia *et al.*, 2003)

Chemical	Composition (%)
SiO_2	9.60
Al_2O_3	2.00
FeO_3	0.70
CaO	43.90
MgO	4.70
SO_3	0.30
Na_2O	0.10
K_2O	0.20
LOI	38.60
Physical test	
Specific gravity kg = dm_3	2.33
BET fineness m_2 = kg	53.00
/average of grains 1 m	0.40
Grains/<3 l m%	0.46

Limestone: Limestone is sedimentary rock with major composition of calcium carbonate or dolomite and used as an ingredient in cement with a higher percentage content of calcium oxide (Table 5).

Limestone has been used in the past study as a mineral filler especially in self-compacted concrete as replacement of either fine aggregate or cement. Guemmadi *et al.* (2009) incorporated fine limestone in concrete with different cement replacement in percentages of 6, 12, 18, 24, 30, 36 and 42% with a different ranging sizes of limestone and compared with the conventional concrete sample for compressive strength and economic feasibility. They found out that limestone fine has an advantage in the concrete which yield a more homogenous mix and improved particle packing, giving a similar compressive strength at same age (28 days) and more economical than the conventional concrete reducing the rate of cement consumption up to 23 while 18% "Finely ground limestone" filler had a higher strength for the same cement content with reduced cost of the concrete. The strength increase was attributed to the quickening effect of the filler in-connection with the "Calcium carboaluminate hydrates" that might have accelerated the increase in hydration. Vuk *et al.* (2001) evaluated the effect in addition of 5% limestone on different properties of cement and found that there was an increase in early age strength development which is due to the addition of limestone and this was due to an improved hydration, in view of the fact that one must

Table 6: Compressive strength, Sorptivity and Porosity of concrete with addition of limestone (Tsivilis *et al.*, 2003)

Sample No.	Replacement (%)	Compressive strength of the cement (28 days N/mm^2)	Concrete compressive strength (28 days, N/mm^2)	Sorptivity, S (mm/min°;5)	Porosity, P (%)
LC1	0	51.1	31.9	0.237	12.48
LC2	5	47.9	27.4	0.238	12.30
LC3	10	48.5	27.3	0.226	12.31
LC4	15	48.1	28.0	0.220	13.14
LC5	20	39.8	28.2	0.228	12.94
LC6	25	40.0	26.5	0.229	13.62
LC7	30	32.9	26.6	0.224	14.64

consider the physical action of limestone and its changes in hydration. This result agreed with the review by Detwiler and Tennis (1996) that 5% limestone added to cement does not affect the performance of Portland cement negatively and grinding the limestone to an appropriate particle size would demonstrate improvement in performance of the cement paste and workability when compared to the same cement without limestone.

Isaia *et al.* (2003) reported that limestone could be utilized as filler in production of high strength concrete (which has to do with the fineness of the limestone particles) and percentages replacement of 12.5, 25 and 50% having different water cement ratios (0.35, 0.50 and 0.65%), they showed that filler effect had a positive influence on the high strength concrete mix at 12.5% replacement and water binder ratio of 0.35 which yield an increase in compressive strength at 91 days more than its counterparts. Tsivilis *et al.* (2003) studied the effect on the addition of limestone with the help of water and air permeability test porosity test and sorptivity with limestone replacing cement from 10-35% and it was found that concrete sample with the addition of limestone showed properties that are similar to samples with Portland cement. It was shown from the result that limestone had a positive effect on the water permeability and sorptivity with limestone up to 15% content. Further increase of limestone content in the concrete would pose a negative effect on the concrete porosity (Table 6).

Bonavetti *et al.* (1999) studied the filler effect of limestone with limestone replacing cement by 0, 9.3 and 18.1% by mass of clinker and tested for 1, 3, 7, 28-150 days. It was found that limestone filler have a significant improvement in the cement efficiency in the concrete sample having a lower water cement ratio due to more hydration of active cementitious material. They concluded that there was early age strength increase by limestone filler but at later age after 1 day there was reduction in strength of about 7-12% at 28 days for limestone replacement level of 9.3 and 18.1. Oey *et al.* (2013) reported that limestone when used as a filler or accelerator in concrete it give two different effect as mineral additive and filler material (filler effect or physical effect) which makes it more beneficial when compared to some other fillers because of its ability and behaviour with cement to form a more cementitious system or to contribute in ion exchange with cement. The performance of limestone with another filler was compared and the result indicates that limestone replacing cement yield a better acceleration in hydration reaction than other filler material in the study.

However, De Schutter (2011) and Mohammed *et al.* (2013), stated that there was no evidence to show that the contribution of chemical improvement of this material is linked to hydration in cement paste. Voglis *et al.* (2005) and Guemmadi *et al.* (2008) disclosed that limestone interact with alumina paste in cement and they noticed a change in strength in the concrete whereby having a higher early strength development with a lower demand for water in the mix than pozzolans. This early strength development was also reported by Matschei *et al.* (2007) and Lothenbach *et al.* (2008). They explained that the addition of limestone as filler rapidly accelerated the early strength development of the mix to produce calcium cabo-aluminate. Mohammed *et al.* (2013) also investigated the “Microstructure and hydration of sustainable self-compacting concrete with different filler types” in view to establish how limestone filler and other filler with the higher replacement of cement will affect the early stage hydration, composition and microstructure. They concluded that a self-compacting concrete can be manufactured with limestone powder particle <65 μm which a compressive strength of 50 MPa with 33% cement replacement that will give an economical and sustainable concrete system.

Heikala *et al.* (2000) studied the effect in replacing Homra (waste from manufacturing of clay brick) with limestone (5, 10, 15, 20%) to investigate the mechanical and physic-chemical of pozzolanic cement paste. The result indicated that addition of limestone reduced the initial and final setting time of the paste and reduces the porosity which fills gaps between the particles of the cement because of the carbon aluminate that might have speed-up the cement setting time. Bonavetti *et al.* (2003) investigated the effect of limestone filler on rate of hydration and the optimum replacement of limestone filler in cement paste up to 20% in different water-cement ratio

(0.25 and 0.50) by the use of "Quadratic statistical model". The result shows an increase in the degree of hydration for a low water-cement ratio with increase in limestone filler content. Ghorab *et al.* (2014) explored the behaviour 10-30% of cement paste and mortars replaced by limestone and concluded that the compressive strength of limestone mortars up to 15% content was seen almost the same strength with the control sample but the strength decreased with higher limestone content.

Similar trend was observed in a report by Schmidt (1992) when cement was replaced with limestone by limestone content, after testing the permeability of air entrained sample that was made with Portland limestone cement and Portland cement they found out that in all parameters that the permeability coefficients for the Portland lime cement concrete was somewhat lower than its counterparts (control) made with only Portland cement. It was not clear if this behaviour was because of the finer particles of the limestone or a more efficient particle in the mix. Based on ideas in respect to replacement some other studies projected the fact and significant effect of fineness of limestone when utilized in replacement of cement in pastes, Hawkins *et al.* (2003) recommended that in application of limestone to cement for a better result, "it is imperative that limestone should be finer than cement, so as to have a competitive result even at considerable replacement up to 8%," Kumar *et al.* (2013) in their research proved that limestone with an average particle size of 3 μ with 10% replacement tend to give strength that is almost same strength with the sample without limestone. Carrasco *et al.* (2005) studied the interaction between two materials limestone filler and blast furnace slag in mortars where limestone filler and blast furnace slag was used to replace Portland cement up to 22% in this regard a two-level factory design was utilized to draw an isorespone curve and the result indicates that flexural and compressive strength studied at different age (2, 7, 14, 28, 90 and 360 days) where affected by the addition of filler. Limestone filler improved the early strength of the sample due to filler effect while blast furnace slag contributed to later age strength by cementing reaction due to pozzolanic effect. Felekoglu *et al.* (2006) study also showed that limestone filler was significant at early strength gain because of the filler effect of limestone whereas at age beyond 28 days curing the pozzolanic material used in that study achieved higher strength than the referenced sample because of pozzolanic effects of the pozzolan.

Lollini *et al.* (2014) stated that when considering replacing cement with limestone in percentages up to 15-30% in concrete mix and the limestone having coarser particle size than cement, the behaviour will yield a reduced strength and a poor durability at all curing age. This findings agreed with a field study by Tennis *et al.* (2011) which revealed that concrete up to 12% limestone content can be used to produce concrete that would be likely similar in the performance to conventional concrete.

SEWAGE SLUDGE ASH

Sewage sludge is a waste produced during the treatment of sewage of municipal wastewater or industrial wastewater with coagulation and flocculation process. This waste is made up of both organic and inorganic substances with major elements like SiO_2, CaO, Al_2O_3, P_2O_5 and other elements (Table 7) while sewage sludge ash is a fine powder which may contain fine sand particles with little or no organic matter after combustion of the sludge (Vouk *et al.*, 2017). This waste material contains particle size of range 1-100 μm with 90% particles smaller than 75 μm which may differ from plant to plant (Table 7). It also depend on the process at which the sludge is been treated and when they are incinerated at a high temperature. It tends to produce an odourless, non-reactive and a fine sewage sludge ash (Shafii *et al.*, 2017; Al-sharif and Attom, 2014; Yusuf *et al.*, 2012; Coutand *et al.*, 2006)

Sewage sludge ash has been reported to have irregular particles and decreases workability due to high specific surface area that brings about a high water requirement in mix when applying to concrete study or mortar, result shows that sewage sludge ash can be utilized up to 25% in concrete or mortar with a strength index after 28 days achieving above 90% which gives a satisfying outcome as either used and classified as filler or Pozzolanic material (low-grade pozzolan) in concrete

Table 7: Chemical composition of sewage sludge ash

	Composition		
Chemicals	Coutand *et al.* (2006)	Fontes *et al.* (2004)	Kosior-Kazberuk (2010)
Fe_2O_3	4.70	12.48	10.32
SiO_2	34.20	39.02	34.68
CaO	20.60	10.12	15.42
MgO	1.90	1.89	2.65
Al_2O_3	12.60	19.09	6.32
P_2O_5	14.80	4.94	18.17
TiO_2	0.90	-	0.41
Na_2O	1.00	1.26	0.70
K_2O	1.70	1.76	-1.30
MnO	0.06	0.09	-
SO_3	2.80	-	0.60
LOI	5.50	-	8.65
(Joo-Hwa and Woon-Kwong. (1989)			
Specific gravity	2.90		
Particle density	0.99 g/cm^3		
Porosity	65.90%		
Water absorption	8.54%		

Table 8: Compressive strength of concrete with addition of sludge ash (Joo-Hwa, 1987; Fontes *et al*., 2016)

	Compressive strength (MPa)									
	Joo-Hwa (1987)				Fontes *et al*. (2016)					
Sludge ash (%)	3 days	7 days	14 days	28 days	1 day	3 days	7 days	28 days	91 days	360 days
Control	24.1	27.5	31.2	34.9	35.5	46.7	51.4	59.5	65.9	75.1
5	21.6	25.9	29.7	33.0	33.1	48.3	51.4	58.0	63.2	74.8
10	21.8	25.2	28.1	31.0	23.7	38.2	42.1	51.3	56.4	67.5
15	17.0	21.5	24.4	27.1	-	-	-	-	-	-
20	14.9	16.8	20.0	23.7	-	-	-	-	-	-

(Coutand *et al*., 2006). Kosior-Kazberuk (2011) used sewage sludge ash as filler in concrete and the result shows that 10-25% content of sewage sludge ash gave an acceptable strength and water absorption, having a compressive strength that is comparable to the reference concrete. Fontes *et al*. (2016) carried out an investigation using sewage sludge ash in high performance concrete, the result showed that 5 and 10% sewage sludge ash replacement was low in compressive strength than the control sample in all curing ages. This behaviour was attributed to filler effect (thinner), showing that the sludge ash acted as filler and not as a binder and it also indicates that the addition of the sludge contributed more on the physical effect (filler effect) than the chemical effect (pozzolanic effect) knowing that there was no strength improvement in all the strength. Addition of sewage sludge ash in the concrete mix had a significant influence on the durability and physical properties, this brought changes in the microstructure of the existing voids of the concrete whereas 5% sewage sludge content had a better strength behaviour among other replacement content (Table 8).

Joo-Hwa (1987) studied the feasibility and effect of sewage sludge ash in both fresh and hardened concrete when used as filler in concrete, it was observed that the workability of the concrete was improved with increased sewage sludge ash and no obvious differences in the segregation of the concrete with the other percentage content of sewage sludge ash. In fresh state, it was shown that sewage sludge was chemically non-reactive with the binder having a reduced strength when sludge was added to the concrete. This proved that sewage sludge ash can be used in concrete as filler (Table 8). Jamshidi *et al*. (2011) studied the use of dried sewage sludge as replacement of fine aggregate in concrete to study the effect of sewage sludge as replacement of fine in concrete performance, it was found that the sewage sludge used in this study had a minimal pozzolanic effect. This further explained that sewage sludge acted more as filler (filler effect) because of low pozzolanic effect and is also a good material to replace fine aggregate in concrete.

CONCLUSION

The use of industrial wastes as filler in concrete has been described. In the majority of research discussed in this study, it is clear that most of this industrial waste have their unique properties when they are used as filler. The particle size of the filler is of great importance and played a great role in improving the workability and in most time little improvement in strength by helping fill existing gap between particles in the concrete, however, for a better result on filler effect especially when replacing fine aggregate, the filler materials should be finer than the normally used fine aggregate or binder. From the preceding study, the following conclusion can be drawn.

The typical range of replacement of filler material to replace fine aggregate for better filler effect varies from 2-30% while replacement above 30% was considered large as it would affect the accuracy and optimum level of their use in concrete/mortar.

The particle size of the filler material had a significant influence on improving workability and in some cases little improvement in strength by fill existing gap between particles in the concrete/mortar, However, for a better result on filler effect, especially, when replacing fine aggregate the filler material should have particle size smaller than 65 μm.

Previous studies showed the use of industrial waste as filler in concrete was basically for non-structural applications. Not much study has been done on their use for structural concrete.

However, there is some other industrial waste materials that needs to be studied in terms of their individual filler effect when used either in concrete or mortar to better understand their contribution as filler, waste material like alum sludge has not gained much attention in this aspect. Although, it is seen as a pozzolanic material (Pozzolanic effect) it still possesses some physical properties that are somewhat as filler (size particle) in concrete or mortar, though it is basically it is basically reactive (pozzolanic) when treated it might still be combined with other industrial waste material (non-reactive materials) as filler in concrete to better understand its filler effect. Furthermore, the use of non-reactive as fine aggregate replacement material to distinguish between filler and pozzolanic effect when using a pozzolanic material have not been really studied. A deeper look into this area will provide a novel outcome which might assist for a better understanding of most of this pozzolanic fillers.

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