Assessment of utilization of ceramic waste as a substitute to concrete constituents – A review

Evaluación de la utilización de desechos cerámicos como sustituto de los componentes del hormigón – Una revisión

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Fecha de Recepción: 13/07/2021
Fecha de Aceptación: 21/03/2022
PAG 69-78

Abstract

Due to high consumption of concrete constituents namely, natural aggregates and cement, their depletion is observed globally. Over the years, many researchers have come up with alternatives to these basic constituents of concrete. Ceramic waste (CW) generated from ceramic industries (industries producing tiles, sanitaryware, ceramic refractories, ceramic insulators, ceramic crockery) have not found any reuse and is deposited as landfills, which further increases land pollution and also give rise to health issues. The CW can be easily grinded as per required size, which have interested many researchers to use it in the production of concrete. Till date CW has been used as partial replacement to cement, fine aggregates and coarse aggregates. This review paper discusses the potential of CW as replacement to concrete constituents in the production of concrete and its effect on mechanical and durability properties. The literature review is carried in three parts – review on use of CW to replace cement, fine aggregates and coarse aggregate. The study shows different researches using different sources of CW having varied properties being used as partial replacement. The effect of replacement on concrete strength and durability is reported.

Keywords: *Ceramic waste, sanitary waste, cement replacement, aggregate replacement, mechanical properties*

Resumen

Debido al alto consumo de componentes del hormigón, esto es, agregados naturales y cemento, cuyo agotamiento se observa globalmente, muchos investigadores, durante años, han estado ideado alternativas para reemplazar estos componentes básicos del hormigón. Aún no han encontrado alguna forma satisfactoria de reutilización de los desechos generados por la industria de cerámicos (ya sea tejas, artefactos sanitarios, refractarios cerámicos, aisladores cerámicos, vajillas cerámicas, etc.) y éstos se depositan en vertederos, aumentando la contaminación del suelo y dando también lugar a problemas de salud. Estos desechos cerámicos se pueden moler fácilmente al tamaño requerido, hecho que ha interesado a algunos investigadores para intentar ocuparlos en la producción del hormigón. Hasta la fecha, estos desechos se han utilizado como reemplazo parcial del cemento, áridos grueso y finos. Este artículo de revisión analiza el potencial de los desechos cerámicos en la producción de hormigón como reemplazo de los componentes y su efecto sobre las propiedades mecánicas y de durabilidad. La revisión de la literatura se llevó a cabo en tres aspectos: revisión sobre el uso de desechos cerámicos para reemplazar parte del cemento, agregados finos y agregados gruesos. El estudio muestra diferentes investigaciones que utilizan diferentes fuentes de desechos cerámicos, con propiedades variadas, utilizados como reemplazo parcial de alguno de los componentes. El estudio informa el efecto de este reemplazo parcial sobre la resistencia y durabilidad del hormigón.

Palabras clave: Desechos cerámicos, desechos de artefactos sanitarios, reemplazo del cemento, reemplazo de los agregados, propiedades mecánicas

1. Introduction

Development of infrastructure have led to high demand of natural resources and as a result high depletion of these resources is observed. Also, industrial development has seen large amount of industrial waste which again is hard to dispose safely without affecting environment. This appears to be a challenging problem to the engineers but with pragmatic approach and implementing new techniques it may be converted into a problem with a solution: using industrial waste to meet the requirement of raw materials for the construction industry. This way, the wastes can be safely used to satisfy the ever-increasing demand of construction materials which will led to a cleaner and green environment. In addition, the replacement of concrete constituents with wastes can be helpful in producing economical concrete which may lower the over-all cost of a project.

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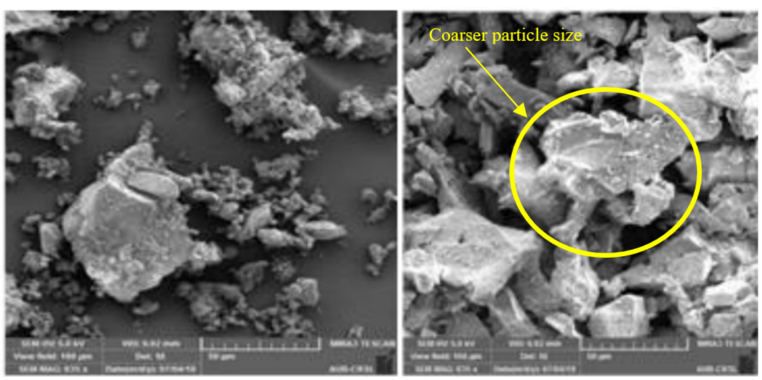
Many research have been done to produce concrete with wastes like slag, fly ash, sugarcane husk, rice husk, rubber wastes, organic waste (Izquierdo et al., 2018), ceramic waste, electronic waste (Dhanabal et al., 2021) etc. by substituting concrete constituent with these wastes, either discretely or in combination. In recent years a lot of research has been done to produce concrete using ceramic wastes as replacement to cement and aggregates. While a comparative study of ceramic utilization as cement replacement and aggregate replacement is done by few authors (Pacheco-torgal and Jalali, 2010); (Bignozzi and Saccani, 2012), it is necessary to review previous study to identify the best use of ceramic waste to replace concrete constituents. This paper reviews work done by various researchers to investigate the potential of ceramic waste by replacing concrete constituents with it. This discussion is divided into three sections – work done by partial replacement of cement, work done by partial replacement of fine aggregates and work done by partial replacement of coarse aggregates. The properties of the CW are also reported. The development of strength and durability are also reported.

2. Literature Review

2.1 Replacement to Cement

CW when crushed to fine powder can be helpful in achieving dense microstructure due to filler effect and the pozzolanic nature of CW can later play a role in imparting strength. This was evident by the works of (Kannan et al., 2017) and (Ding et al., 2020). (Ding et al., 2020) investigated the pozzolanic activity of household ceramic (HC) waste and clay brick (CB) waste using Frattini test and SAI test. A strong linear correlation between these tests was observed for HC (R = 0.958). However, for CB, negative correlation was established which was conclusive with the XRD test which showed CB powder with high degree of crystallinity.



(a) (b)

Figure 1. *SEM images for (a) cement and (b) CW (reproduced from (AlArab et al., 2020)*

The study on use of CW with different particle size (< 45 µm, 45-90µm and >90µm) to produce cement clinker revealed that the particles less than 90µm had better reactivity and higher burnability compared to traditional cement clinker (Puertas et al., 2008). The particle size of CW used to replace cement were coarser than the cement particles as confirmed from the studies of scanning electron microscope images by (AlArab et al., 2020), (Li et al., 2019) and (Mohit and Sharifi, 2019); as shown in (Figure 1). This coarse nature of CW particles may tend to reduce filler effect and pozzolanic reactivity (AlArab et al., 2020)). Moreover, CW particles consist of irregular and angular particles similar to cement particles (Kannan et al., 2017). The specific surface area (SSA) of CW powders reported by various authors is compiled in (Table 1) and in most of the studies, SSA of CW is higher compared to SSA of cement. Thus, higher surface area is also an indication of higher reactivity. The fineness of powder may affect the mechanical and durability properties (Betancourt and Martirena, 2011). The clinker and cement containing CW as an alternative raw material had similar characterization as of regular cement (Puertas et al., 2010). (Figure 2) shows ternary diagram of commonly used supplementary cementitious material recreated from (Bignozzi and Saccani, 2012).

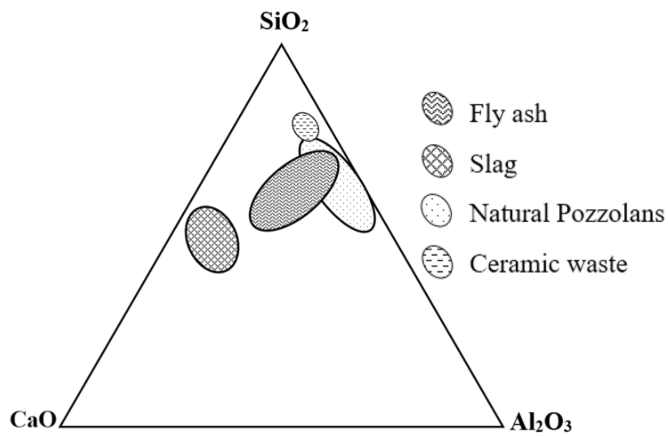


Figure 2. *Ternary diagram of commonly used SCM*

Table 1. *Chemical composition of CW used as cement*

Author	*Chemical Composition (% by weight)*					*SSA# (m^2/kg)*
	SiO_2	*Al_2O_3*	*Cao*	*SO_3*	*LOI*	
(AlArab et al., 2020)	67.30	19.80	2.30	0.10	NIL	365 (0.70) ^
(Behforouz et al., 2020)	63.29	18.29	4.46	0.10	1.61	325 (1.03)
(Ding et al., 2020) For House ceramic	71.03	18.22	0.57	-	-	530 (1.60)
(Ding et al., 2020) For ceramic brick waste	60.60	20.35	0.17	-	-	690 (2.09)
(L. Li et al., 2020)	61.72	22.31	6.67	0.07	3.96	458 (1.33)
(Mohit and Sharifi, 2019)	64.04	21.00	1.29	0.11	1.1	554 (1.78) $
(Lasseuguette et al., 2019) For white ceramic	68.90	19.80	7.00	-	0.20	-
(Lasseuguette et al., 2019) For red ceramic	60.50	26.90	1.00	-	0.20	-
(El-Dieb and Kanaan, 2018)	68.60	17.00	1.70	0.12	1.78	555 (1.46) $
(Kannan et al., 2017)	69.40	18.20	1.24	<1	<1	555 (-)
(Ali et al., 2016)	69.40	18.20	1.24	-	-	555 (1.46)
(Cheng et al., 2014)	69.02	16.04	0.63	-	5.23	-
(Reiterman et al., 2014)	63.45	13.98	8.18	-	-	6360 (1.67)
(Heidari and Tavakoli, 2013)	68.85	18.53	1.57	0.06	0.48	34100 (117.58) ^
(Pacheco-torgal and Jalali, 2010) for White paste sanitary waste	65.80	22.20	0.10	-	-	-
(Puertas et al., 2010)	66.00	14.20	6.10	0.04	0.43	-
(Ay, 2000)	63.29	18.29	4.46	0.10	1.61	368 (-) $

#SSA = Specific Surface area (Values in parathesis indicates ratio of SSA of CW to cement)
^SSA determined by Brunauer–Emmett–Teller (BET) method
$SSA determined by Blaine method

(Pacheco-torgal and Jalali, 2010) examined the use of CW powder, as fine as <75μm, to determine strength and durability properties. The mix were prepared by replacing cement with 20% of each four source of CW: Ceramic Bricks (CB), White Stoneware Twice-Fired (WSTF), Sanitary Ware (SW) and White Stoneware Once-Fired (WSOF).

The mix with CB waste had better mechanical properties which indicated higher pozzolanic reactivity. The results had larger differences at early age as compared to smaller differences at later curing age. Vacuum water absorption, capillary water absorption, Oxygen permeability, water permeability, Chloride diffusion test and accelerated aging test were performed to study the durability properties of the mixes. All mixes with CWs performed better than control mix.

(Heidari and Tavakoli, 2013) confirmed pozzolanic activity of ceramic powder obtained by grounding recycled ceramic ground tiles and studied mechanical properties of concrete. It was observed that with higher proportion of CW, the compressive strength reduced. Also, at later stages, minor strength loss was observed indicating good pozzolanic reactivity. The use of CW also helped in reducing water absorption capacity, as every concrete mix with CW showed better performance as compared to control mix.

(Reiterman et al., 2014) experimentally observed basic and hygric properties of concrete mixtures with partial substitution of cement by fine ceramic powder (FCP). The reduction in water absorption was observed for the mixes with FCP replacement up to 10% of cement and for these mixes compressive strength at 28 days was slightly higher compared to control mix with no FCP. The mixes with higher content of FCP showed reduction in strength due to lower bulk density than control mix. (Kannan et al., 2017) evaluated high performance concrete (HPC) by replacing cement with CW and observed lower compressive strength at early age while comparable compressive strength at later ages for mixes containing CW. These mixes showed better durability performance. Microstructural investigations confirmed no significant difference in the hydration components in mixtures incorporating cement waste and the reference concrete mixture. The pozzolanic activity of CW was studied by Frattini test and suggested noticeable reactivity viz. due to filler effect and pozzolanic effect.

Moreover, CW has been used with other supplementary cementitious material to study the synergy between these materials. (AlArab et al., 2020) investigated the synergy effect of CW with slag and (Cheng et al., 2014) studied durability properties of concrete with CW and fly ash.

(Table 1) shows main chemical composition of the CW used by various researchers. With such high silica content, it can also be used as a replacement silica source for alkali activated cements (Torres-Carrasco and Puertas, 2017). For all the above reported values in (Table 1),

$$SiO_2 + Al_2O_3 + Fe_2O_3 > 70\%$$
$$SO_3 < 3\%$$
$$LOI < 10\%$$

This indicates pozzolanic reactivity as per ASTM C618-08a.

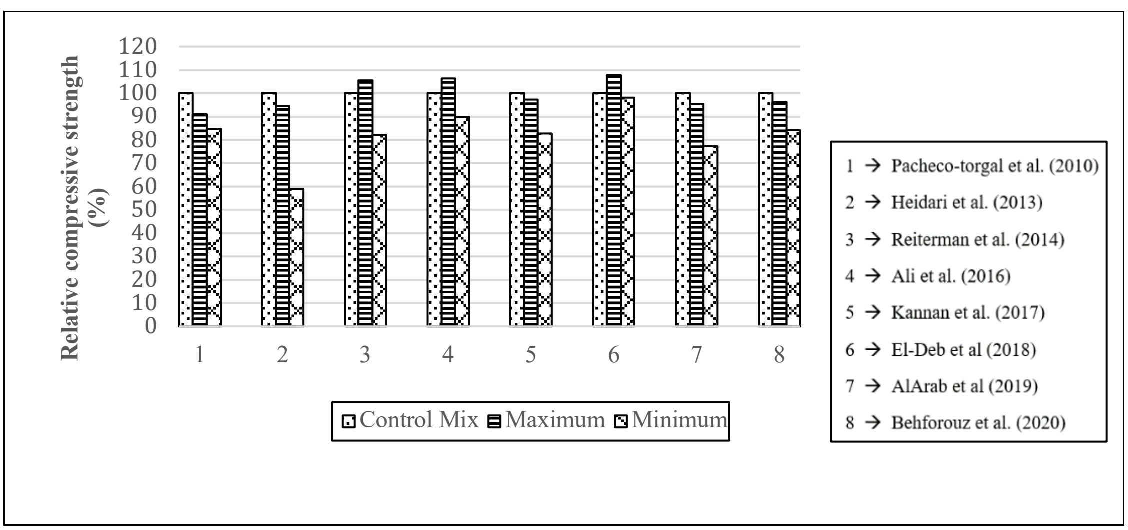


Figure 3. *Relative 28-day compressive strength of concrete mixes with CW as cement*

(Figure 3) shows variation in 28-day compressive strength of the mixes prepared with partial replacement of cement with CW, relatively with a control mix with no CW. The strength of control concrete mix is compared with strength of concrete mix with ceramic waste having highest strength (maximum) and the lowest strength (minimum). The compressive strength at 28 days is at par with the control mix and the loss in strength is very negligible. From above literature review it can be said that the replacement of cement by CW results into lower or similar strength at early age and later the strength increases. This is because replacement of cement lowers the strength at early stage but at later stages due to the pozzolanic activity of CW with hydrated cement products, the strength increases.

2.2 Replacement to Fine Aggregate

(López et al., 2007) investigated physical and mechanical properties of concrete mix by replacing conventional sand with white ceramic powder. The compression, flexural strength and Brazilian (tensile splitting strength) test showed that the concrete mix with CW had better compressive strength and same mechanical characteristics as that of control mix with conventional sand. (Torkittikul and Chaipanich, 2010) assessed the effect of CW on fresh and hardened properties of concrete by replacing natural sand with CW. It was observed that for concrete with CW, density was lower than control mix without CW. These concrete mixes also showed higher compressive strength compared to control mix.

***Table 2.** Properties of fine CW used as partial replacement to fine aggregate*

Author	Specific Gravity	WA@ (%)	FM#	Porosity (%)
(Guendouz and Boukhelkhal, 2019)	2.45	4.25	2.33	50
(Awoyera et al., 2018)	2.26	2.52	2.20	-
(Etxeberria and Gonzalez-Corominas, 2018)	2.09	12.55	-	-
(Siddique et al., 2017)	2.40	2.50	2.73	-
(Alves et al., 2014) Sanitary ware aggregates	2.97	0.20	-	-
(Tavakoli et al., 2013)	2.35	7.00	3.10	-
(Halicka et al., 2013)	2.36	1.53	-	-
(Pacheco-torgal and Jalali, 2010)	2.21	6.10	-	-
(Binici, 2007)	2.44	0.71	2.68	44.2
(López et al., 2007)	2.40	-	-	-

@Water Absorption *#Fineness Modulus*

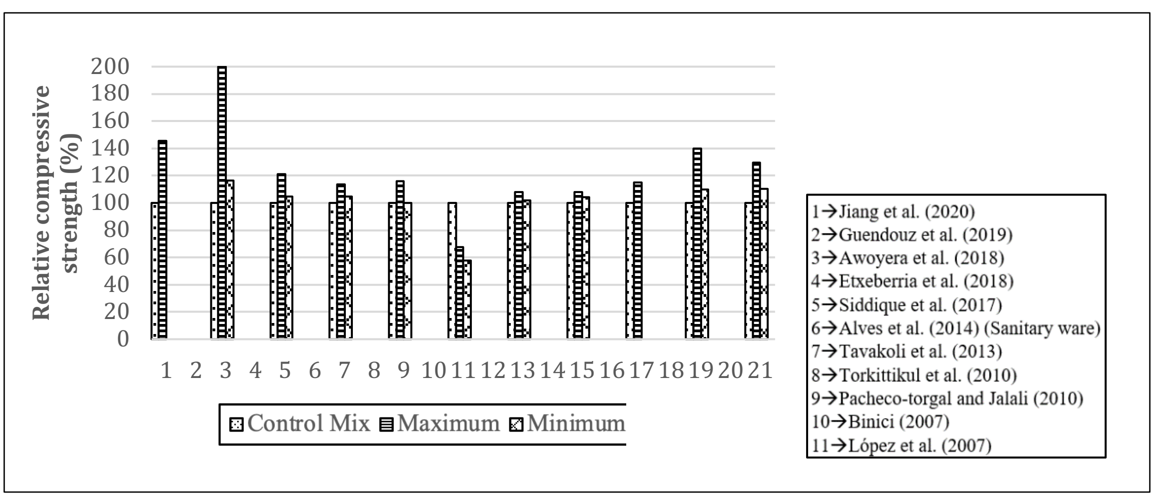


Figure 4. Relative 28-day compressive strength of concrete mixes with CW as fine aggregates

(Pacheco-torgal and Jalali, 2010) examined ceramic-based concrete by replacing natural sand with ceramic sand to determine strength and durability properties. The concrete mix with CW showed higher strength than control mix. The CW based concrete showed better results in capillary water absorption; almost 50% less compared to control concrete mix. The CW based concrete performed better than control mix in oxygen permeability test and chloride diffusion test. (Siddique et al., 2017) examined fresh and hard properties of the concrete produced by replacing natural sand with bone-china aggregate as fine aggregate. It was observed that with increase in the content of CW, fresh density increased & air content decreased however, compressive strength and bleeding increased.

The basic properties of CW used as fine aggregate as reported by various authors is compiled in (Table 2). The specific gravity is in the range of 2-2.5 which is very similar to natural fine aggregates. (Figure 4 shows variation in 28-day compressive strength of the mixes prepared with partial re-placement of fine aggregates with CW, relatively with a control mix with no CW. The literature review suggests that the replacement of traditional fine aggregates with CW aggregate does not compromise with the compressive strength and also performs better from durability aspects. The increase in strength can be attributed to the fact that fines from CW fills the voids and helps in achieving dense matrix which over-all increases compressive strength.

2.3 Replacement to Coarse Aggregate

The CW obtained from the field has to be crushed to get coarse aggregate-sized particles. The basic properties of the crushed ceramic coarse aggregate reported by various authors is compiled in (Table 3).

The fresh and hardened properties of the concrete prepared by replacing crushed stone aggregate (obtained from ceramic electrical insulator industrial waste) was studied by (Senthamarai and Devadas, 2005) with CW aggregate and observed more workability than conventional concrete due to smooth surface of CW aggregate. Over-all, it was observed that the properties of CW aggregate concrete were similar to conventional concrete. The concrete with CW showed better permeation characteristics and with the decrease in water/cement ratio performance decreases (Senthamarai et al., 2011).

(Pacheco-torgal and Jalali, 2010) examined ceramic-based concrete by replacing coarse granite aggregate with ceramic coarse aggregate to determine strength and durability properties. The concrete mix with CW showed higher strength than control mix but underperformed in durability properties. (Medina et al., 2012a) partially substituted natural coarse aggregate with recycled ceramic aggregate (obtained from sanitaryware manufacturer) to study physical and mechanical properties of structural concrete. The mineralogical composition showed that interfacial transition zone (ITZ) between paste and recycled ceramic aggregate was more compact, narrower and less porous than that between paste-gravel. It was observed that concrete with CW showed higher performance in compressive and tensile strength tests.

(Rashid et al., 2017) partially replaced conventional coarse aggregate by CW aggregate to experimentally assess fresh and hardened properties of the concrete thus produced. It was observed that workability decreased and compressive strength increased with increase in proportion of CW (attributed to glassy surface and rough shape of CW aggregate). Also, by using analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS), concrete made with 30% replacement was selected as best sustainable recycled concrete.

***Table 3.** Properties of crushed CW used as partial replacement to coarse aggregate*

Author	*Specific Gravity*	*WA@ (%)*	*CV* (%)*	*FM***
(Ogawa et al., 2020)	-	-	*368*	-
(Keshavarz and Mostofinejad, 2019) Porcelain tile	*2.362*	*0.84*	-	-
(Keshavarz and Mostofinejad, 2019) Red ceramic	*2.13*	*8.6*	-	-
(Zareei et al., 2019)	*2.46*	*16.6*	-	-
(Pitarch et al., 2019) Tile ceramic waste (TCW)	*2.78*	*8.93*	*15.50#*	*5.95*
(Pitarch et al., 2019) Ceramic sanitaryware (CSW)	*2.28*	*1.83*	*7.30#*	*6.19*
(Awoyera et al., 2018)	*2.31*	*0.55*	*20.86*	*6.88*
(Nepomuceno et al., 2018)	*2.16*	*11.5*	*35.40$*	
(Etxeberria and Gonzalez-Corominas, 2018)	*1.79*	*17.82*	*34.62*	-
(Siddique et al., 2018)	*2.40*	*2.5*	-	
(Rashid et al., 2017)	*2.30*	*17.39*	*27.00*	*7.95*
(Zegardło et al., 2016)	*2.36*	*1.5*	*8.90*	-
(Anderson et al., 2016)	*2.26*	*5.5*	*24.90*	-
(Tavakoli et al., 2013)	*2.33*	*4.8*	-	-
Medina et al. (2012)	*2.39*	*0.55*	-	-
(Pacheco-torgal and Jalali, 2010)	*2.26*	*6.00*	-	-
(Suzuki et al., 2009)	*2.27*	*9.31*	*21.40*	*6.51*
(Correia et al., 2006)	*2.273*	*12.00*	-	-
(De Brito et al., 2005)	*2.62*	*12.00*	-	-
(R. M. Senthamarai and Devadas Manoharan, 2005)	*2.45*	*0.72*	*27.00*	*6.88*

@Water Absorption **Crushing Value* ***Fineness Modulus*
#Resistance to wear (wt%) *$Crush resistance (%)*

(Ogawa et al., 2020) investigated use of porous CW as internal curing agent in steam-cured concrete using fly ash by replacing natural coarse aggregate in the replacement ratio of 0%, 10%, and 20% by volume. This porous CW coarse aggregate significantly improved compressive strength and carbonation resistance of concrete. (Yasin Mousavi et al., 2020) successfully replaced natural coarse aggregate with ceramic tile waste aggregate and ceramic sanitary waste aggregate to produce high strength concrete up to 60 MPa. With the replacement levels of up to 30%, the HSC produced from the CW had comparable compressive strength with plain HSC without CW aggregates. Due to high water absorptivity of CW aggregates, the water absorption of HSC produced from it was also higher.

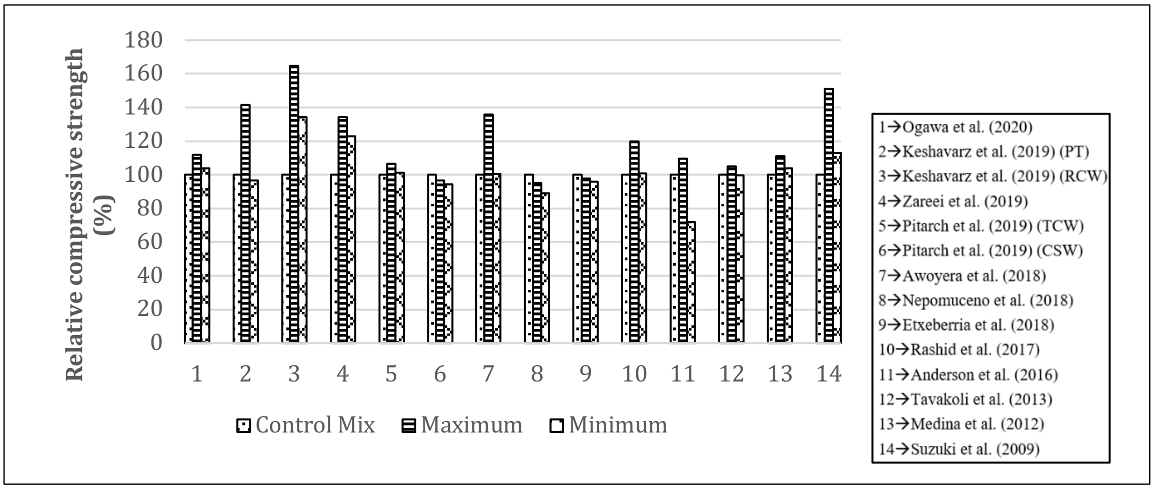


Figure 5. *Relative 28-day compressive strength of concrete mixes with CW as coarse*

3. Conclusions

This literature review on ceramic waste (CW) has identified it as a potential replacement to concrete constituents. Following conclusions are drawn from this study:

(i) The major chemical composition of the CW includes Silica (>60%) and Alumina (> 15%) with (SiO_2 +Al_2O_3 +Fe_2O_3) content more than 70%.
(ii) The specific surface area of the CW powder is higher than the cement which implies higher reactivity.
(iii) CW has been successfully used to replace cement content partially without significantly loss in compressive strength. However, as reported, CW obtained from different sources may have variation in material properties. Thus, it becomes highly essential to characterize the CW.
(iv) The basic material properties like specific gravity, water absorption and fineness modulus are nearly similar to that of natural fine aggregates.
(v) The replacement of fine aggregates with CW, as reported, in many cases have improved the over-all performance of the concrete. This is due to the fact that CW as fines helps improving workability and later due to their pozzolanic nature imparts strength to the mix.
(vi) The replacement of coarse aggregate with CW has observed lower workability due to the rough and angular surface of CW aggregate, however, compressive strength was improved.

The use of CW as substitution to fine aggregates is more preferable as it aids in achieving better workability, compressive strength and durability than conventional aggregates.

4. References

AlArab, A.; Hamad, B.; Chehab, G.; Assaad, J. J. (2020). Use of Ceramic-Waste Powder as Value-Added Pozzolanic Material with Improved Thermal Properties. Journal of materials in civil engineering, 32(9): 1–10, https://doi.org/10.1061/(ASCE)MT.1943-5533.0003326

Ali, S. T.; EL-Dieb, A. S.; Aboubakr, S. H.; Reda Taha, M. M. (2016). Utilization of ceramic waste powder in self-compacting concrete. Sustainable Construction Materials and Technologies, 2016-Augus: https://doi.org/10.18552/2016/SCMT4S116

Alves, A. V.; Vieira, T. F.; De Brito, J.; Correia, J. R. (2014). Mechanical properties of structural concrete with fine recycled ceramic aggregates. Construction and Building Materials, 64: 103–113, https://doi.org/10.1016/j.conbuildmat.2014.04.037

Anderson, D. J.; Smith, S. T.; Au, F. T. K. (2016). Mechanical properties of concrete utilising waste ceramic as coarse aggregate. Construction and Building Materials, 117: 20–28, https://doi.org/10.1016/j.conbuildmat.2016.04.153

Awoyera, P. O.; Akinmusuru, J. O.; Dawson, A. R.; Ndambuki, J. M.; Thom, N. H. (2018). Microstructural characteristics, porosity and strength development in ceramic-laterized concrete. Cement and Concrete Composites, 86: 224–237, https://doi.org/10.1016/j.cemconcomp.2017.11.017

Ay, N. (2000). The use of waste ceramic tile in cement production. Cement and Concrete Research, 30: 497–499, https://doi.org/10.1016/S0008-8846(00)00202-7

Bedoya, C.; Dzul, L. (2015). Concrete with recycled aggregates as urban sustainability project. Revista Ingenieria de Construccion, 30(2): 99–108, https://doi.org/10.4067/s0718-50732015000200002

Behforouz, B.; Memarzadeh, P.; Eftekhar, M.; Fathi, F. (2020). Regression and ANN models for durability and mechanical characteristics of waste ceramic powder high performance sustainable concrete. Computers and Concrete, 25(2): 119–132, https://doi.org/10.12989/cac.2020.25.2.119

Betancourt, D.; Martirena, F. (2011). Influencia de la finura del molido del carbonato de calcio. Revista Ingeniería de Construcción, 26(03): 269–283, https://doi.org/10.4067/S0718-50732011000300002

Bignozzi, M. C.; Saccani, A. (2012). Ceramic waste as aggregate and supplementary cementing material: A combined action to contrast alkali silica reaction (ASR). Cement and Concrete Composites, 34(10): 1141–1148, https://doi.org/10.1016/j.cemconcomp.2012.07.001

Binici, H. (2007). Effect of crushed ceramic and basaltic pumice as fine aggregates on concrete mortars properties. Construction and Building Materials, 21(6): 1191–1197, https://doi.org/10.1016/j.conbuildmat.2006.06.002

Cheng, Y.; Huang, F.; Li, G. L.; Xu, L.; Hou, J. (2014). Test research on effects of ceramic polishing powder on carbonation and sulphate-corrosion resistance of concrete. Construction and Building Materials, 55: 440–446, https://doi.org/10.1016/j.conbuildmat.2014.01.023

Correia, J. R.; De Brito, J.; Pereira, A. S. (2006). Effects on concrete durability of using recycled ceramic aggregates. Materials and Structures/Materiaux et Constructions, 39(286): 169–177, https://doi.org/10.1617/s11527-005-9014-7

De Brito, J.; Pereira, A. S.; Correia, J. R. (2005). Mechanical behaviour of non-structural concrete made with recycled ceramic aggregates. Cement and Concrete Composites, 27(4): 429–433, https://doi.org/10.1016/j.cemconcomp.2004.07.005

Dhanabal, P.; Sushmitha, K. S.; Narendra Reddy, P. (2021). Study on properties of concrete with electronic waste Estudio sobre las propiedades del hormigón con residuos electrónicos. Revista Ingenieria de Construccion, 36(1): 48–58, https://doi.org/10.4067/S0718-50732021000100048

Ding, Y.; Dong, H.; Cao, M.; Azevedo, C. (2020). Recycled household ceramic waste in eco-efficient cement: A case study 2020. In A. K. Fernando Pacheco-Torgal, Yining Ding, Francesco Colangelo, Rabin Tuladhar (Ed.), Advances in Construction and Demolition Waste Recycling. Woodhead Publishing https://doi.org/10.1016/B978-0-12-819055-5.00017-6

El-Dieb, A. S.; Kanaan, D. M. (2018). Ceramic waste powder an alternative cement replacement – Characterization and evaluation. Sustainable Materials and Technologies, 17: e00063, https://doi.org/10.1016/j.susmat.2018.e00063

Etxeberria, M.; Gonzalez-Corominas, A. (2018). The assessment of ceramic and mixed recycled aggregates for high strength and low shrinkage concretes. Materials and Structures/Materiaux et Constructions, 51(5): https://doi.org/10.1617/s11527-018-1244-6

Guendouz, M.; Boukhelkhal, D. (2019). Properties of flowable sand concrete containing ceramic wastes. Journal of Adhesion Science and Technology, 33(24): 1–23, https://doi.org/10.1080/01694243.2019.1653594

Halicka, A.; Ogrodnik, P.; Zegardlo, B. (2013). Using ceramic sanitary ware waste as concrete aggregate. Construction and Building Materials, 48: 295–305, https://doi.org/10.1016/j.conbuildmat.2013.06.063

Heidari, A.; Tavakoli, D. (2013). A study of the mechanical properties of ground ceramic powder concrete incorporating nano-SiO2 particles. Construction and Building Materials, 38: 255–264, https://doi.org/10.1016/j.conbuildmat.2012.07.110

Izquierdo, I. S.; Izquierdo, O. S.; Ramalho, M. (2018). Physical and mechanical properties of concrete using residual powder from organic waste as partial cement replacement. Revista Ingenieria de Construccion, 33(3): 229–240, https://doi.org/10.4067/S0718-50732018000300229

Kannan, D. M.; Aboubakr, S. H.; EL-Dieb, A. S.; Reda Taha, M. M. (2017). High performance concrete incorporating ceramic waste powder as large partial replacement of Portland cement. Construction and Building Materials, 144: 35–41, https://doi.org/10.1016/j.conbuildmat.2017.03.115

Keshavarz, Z.; Mostofinejad, D. (2019). Porcelain and red ceramic wastes used as replacements for coarse aggregate in concrete. Construction and Building Materials, 195: 218–230, https://doi.org/10.1016/j.conbuildmat.2018.11.033

Lasseuguette, E.; Burns, S.; Simmons, D.; Francis, E.; Chai, H. K.; Koutsos, V.; Huang, Y. (2019). Chemical, microstructural and mechanical properties of ceramic waste blended cementitious systems. Journal of Cleaner Production, 211: 1228–1238, https://doi.org/10.1016/j.jclepro.2018.11.240

Li, L. G.; Zhuo, Z. Y.; Zhu, J.; Chen, J. J.; Kwan, A. K. H. (2019). Reutilizing ceramic polishing waste as powder filler in mortar to reduce cement content by 33% and increase strength by 85%. Powder Technology, 355: 119–126, https://doi.org/10.1016/j.powtec.2019.07.043

Li, L.; Liu, W.; You, Q.; Chen, M.; Zeng, Q. (2020). Waste ceramic powder as a pozzolanic supplementary filler of cement for developing sustainable building materials. Journal of Cleaner Production, 259: https://doi.org/10.1016/j.jclepro.2020.120853

López, V.; Llamas, B.; Juan, A.; Morán, J. M.; Guerra, I. (2007). Eco-efficient Concretes: Impact of the Use of White Ceramic Powder on the Mechanical Properties of Concrete. Biosystems Engineering, 96(4): 559–564, https://doi.org/10.1016/j.biosystemseng.2007.01.004

Medina, C.; Frías, M.; Sánchez De Rojas, M. I. (2012). Microstructure and properties of recycled concretes using ceramic sanitary ware industry waste as coarse aggregate. Construction and Building Materials, 31: 112–118, https://doi.org/10.1016/j.conbuildmat.2011.12.075

Medina, C.; Sánchez De Rojas, M. I.; Frías, M. (2012). Reuse of sanitary ceramic wastes as coarse aggregate in eco-efficient concretes. Cement and Concrete Composites, 34(1): 48–54, https://doi.org/10.1016/j.cemconcomp.2011.08.015

Mohit, M.; Sharifi, Y. (2019). Thermal and microstructure properties of cement mortar containing ceramic waste powder as alternative cementitious materials. Construction and Building Materials, 223: 643–656, https://doi.org/10.1016/j.conbuildmat.2019.07.029

Nepomuceno, M. C. S.; Isidoro, R. A. S.; Catarino, J. P. G. (2018). Mechanical performance evaluation of concrete made with recycled ceramic coarse aggregates from industrial brick waste. Construction and Building Materials, 165: 284–294, https://doi.org/10.1016/j.conbuildmat.2018.01.052

Ogawa, Y.; Bui, P. T.; Kawai, K.; Sato, R. (2020). Effects of porous ceramic roof tile waste aggregate on strength development and carbonation resistance of steam-cured fly ash concrete. Construction and Building Materials, 236: 117462, https://doi.org/10.1016/j.conbuildmat.2019.117462

Pacheco-torgal, F.; Jalali, S. (2010). Reusing ceramic wastes in concrete. Construction and Building Materials, 24(5): 832–838, https://doi.org/10.1016/j.conbuildmat.2009.10.023

Pitarch, A. M.; Reig, L.; Tomás, A. E.; López, F. J. (2019). Effect of Tiles, Bricks and Ceramic Sanitary-Ware Recycled Aggregates on Structural Concrete Properties. Waste and Biomass Valorization, 10(6): 1779–1793, https://doi.org/10.1007/s12649-017-0154-0

Puertas, F.; García-Díaz, I.; Barba, A.; Gazulla, M. F.; Palacios, M.; Gómez, M. P.; Martínez-Ramírez, S. (2008). Ceramic wastes as alternative raw materials for Portland cement clinker production. Cement and Concrete Composites, 30(9): 798–805, https://doi.org/10.1016/j.cemconcomp.2008.06.003

Puertas, F.; García-Díaz, I.; Palacios, M.; Gazulla, M. F.; Gómez, M. P.; Orduña, M. (2010). Clinkers and cements obtained from raw mix containing ceramic waste as a raw material. Characterization, hydration and leaching studies. Cement and Concrete Composites, 32(3): 175–186, https://doi.org/10.1016/j.cemconcomp.2009.11.011

Rashid, K.; Razzaq, A.; Ahmad, M.; Rashid, T.; Tariq, S. (2017). Experimental and analytical selection of sustainable recycled concrete with ceramic waste aggregate. Construction and Building Materials, 154: 829–840, https://doi.org/10.1016/j.conbuildmat.2017.07.219

Reiterman, P.; Holčapek, O.; Čáchová, M.; Vogel, F.; Jogl, M.; Konvalinka, P. (2014). Basic and Hygric Properties of Concrete Containing Fine Ceramic Powder. Advanced Materials Research, 897: 188–191, https://doi.org/10.4028/www.scientific.net/amr.897.188

Senthamarai, R. M.; Devadas Manoharan, P. (2005). Concrete with ceramic waste aggregate. Cement and Concrete Composites, 27(9–10): 910–913, https://doi.org/10.1016/j.cemconcomp.2005.04.003

Senthamarai, R.; Manoharan, P. D.; Gobinath, D. (2011). Concrete made from ceramic industry waste: Durability properties. Construction and Building Materials, 25(5): 2413–2419, https://doi.org/10.1016/j.conbuildmat.2010.11.049

Siddique, S.; Shrivastava, S.; Chaudhary, S. (2017). Influence of ceramic waste on the fresh properties and compressive strength of concrete. European Journal of Environmental and Civil Engineering, 8189(January): 1–14, https://doi.org/10.1080/19648189.2016.1275985

Siddique, S.; Shrivastava, S.; Chaudhary, S.; Gupta, T. (2018). Strength and impact resistance properties of concrete containing fine bone china ceramic aggregate. Construction and Building Materials, 169: 289–298, https://doi.org/10.1016/j.conbuildmat.2018.02.213

Suzuki, M.; Seddik Meddah, M.; Sato, R. (2009). Use of porous ceramic waste aggregates for internal curing of high-performance concrete. Cement and Concrete Research, 39(5): 373–381, https://doi.org/10.1016/j.cemconres.2009.01.007

Tavakoli, D.; Heidari, A.; Karimian, M. (2013). Properties of concretes produced with waste ceramic tile aggregate. Asian Journal of Civil Engineering, 14(3): 369–382,

Torkittikul, P.; Chaipanich, A. (2010). Utilization of ceramic waste as fine aggregate within Portland cement and fly ash concretes. Cement and Concrete Composites, 32(6): 440–449, https://doi.org/10.1016/j.cemconcomp.2010.02.004

Torres-Carrasco, M.; Puertas, F. (2017). Alkaline activation of different aluminosilicates as an alternative to Portland cement: Alkali activated cements or geopolymers. Revista Ingeniería de Construcción, 32(2): 05–12, https://doi.org/10.4067/S0718-50732017000200001

Yasin Mousavi, S.; Tavakkoli, A.; Jahanshahi, M.; Dankoub, A. (2020). Performance of high-strength concrete made with recycled ceramic aggregates. International Journal of Engineering Transactions C: Aspects, 33(6): 1085–1093, https://doi.org/10.5829/ije.2020.33.06c.05

Zareei, S. A.; Ameri, F.; Shoaei, P.; Bahrami, N. (2019). Recycled ceramic waste high strength concrete containing wollastonite particles and micro-silica: A comprehensive experimental study. Construction and Building Materials, 201: 11–32, https://doi.org/10.1016/j.conbuildmat.2018.12.161

Zegardło, B.; Szeląg, M.; Ogrodnik, P. (2016). Ultra-high strength concrete made with recycled aggregate from sanitary ceramic wastes – The method of production and the interfacial transition zone. Construction and Building Materials, 122: 736–742, https://doi.org/10.1016/j.conbuildmat.2016.06.112.