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Study of Using of Recycled Brick Waste (RBW) to produce Environmental Friendly Concrete: A Review

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ABSTRACT

Several million tons of solid waste are produced each year due to construction and demolition activities worldwide, and brick waste is one of the widest wastes. Recently, a growing number of studies have been conducted on using recycling brick waste (RBW) to produce environmentally friendly concrete. The use of brick waste (BW) as potential partial cement or aggregate replacement materials is summarized in this review, where the performance is discussed in the form of the mechanical strength and properties related to the durability of concrete. It was found that, because of the pozzolanic activity of clay brick powder, it can be utilized as a cement substitute in replacement levels up to 10%. Whereas for natural coarse aggregate, recycled aggregate can be used instead of it, but at a limited replacement level. Concrete manufacturing from recycled aggregate can give adequate strength and can be suitable for producing medium or low strength concrete. On the other side, the utilization of fine recycled brick waste as aggregate in concrete manufacturing provides development of the properties of concrete. It develops the durability of concrete in some cases when used with replacement level up to 10% by the weight of fine aggregate.

Keywords: Environmentally Friendly Concrete, Brick Waste (BW), Clay Brick Powder (CBP), Recycled Brick Aggregate (RBA).

دراسة استخدام مخلفات الطابوق المعاد تدويرها لإنتاج خرسانة صديقة للبيئة: مراجعة

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الخلاصة

النفايات الصلبة الناتجة عن انشطة البناء والهدم تصل الى عدة ملايين من الأطنان على مستوى العالم، وتعد مخلفات الطابوق واحدة من أكثر النفايات انتشارًا. في الآونة الأخيرة، كان هناك عدد متزايد من الدراسات التي أجريت على استخدام مخلفات الطابوق لإعادة المعاد تدويرها لإنتاج خرسانة صديقة للبيئة. تم تلخيص استخدام مخلفات الطابوق كاستبدال جزئي للسمنت أو

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مواد بديلة للركام في هذه المراجعة حيث تمت مناقشة الأداء في حيث القوة الميكانيكية والخصائص المتعلقة بمتانة الخرسانة. ووجد أنه بسبب النشاط البوزولاني لمسحوق الطابوق الطيني، فيمكن استخدامه كبديل للسمنت في مستوى الاستبدال حتى 10٪. في حين أنه بالنسبة للركام الخشن الطبيعي ، فيمكن استخدام الركام المعاد تدويره بدلاً منه ، ولكن في مستوى استبدال محدود. يمكن أن يعطي تصنيع الخرسانة من الركام المعاد تدويره قوة كافية ويمكن أن يكون مناسبًا لإنتاج الخرسانة ذات القوة المتوسطة أو المنخفضة. على الجانب الآخر ، فإن استخدام مخلفات الطابوق المعاد تدويرها كركام ناعم في تصنيع الخرسانة، فانه يوفر تطوير خصائص الخرسانة ويطور متانة الخرسانة في بعض الحالات عندما يكون مستوى الاستبدال يصل إلى 10٪ من وزن الركام الناعم.
الكلمات الرئيسية: السمنت الصديق للبيئة، مخلفات الطابوق، مسحوق الطابوق الطيني، ركام الطابوق المعاد تدويرها.

1. INTRODUCTION

Concrete is the common undisputable and necessary material that is used in the creation of infrastructure all over the world. It is one of the oldest and most popularly used building materials in the world today. It is considered inexpensive, strong, easily obtainable. In addition, it is a durable material. In several laboratories, many kinds of concrete (High Volume Fly Ash Concrete (HVFAC), High Strength Concrete (HSC), High performance Concrete (HPC), Fiber Reinforced Concrete (FRC), and others) were investigated and taken to the field to meet the particular needs. On the other hand, the manufacturing of concrete causes environmental pollution and consumption of a non-renewable resource, for example, natural aggregate. Annually, concrete manufacturing is projected as 11 billion metric tons, of which 70 percent to 75 percent is aggregate; water is 15 percent; whereas for the cementitious binder is 10 percent to 15 percent **(Mobili et al., 2018; Rani and Jenifer, 2016)**. Portland cement clinker is considered the most widely cementitious binder utilized in concrete, but its manufacture is energy intensive **(Rani and Jenifer 2016)**. The manufacture of one ton of Portland cement clinker releases around 850 Kg of CO_2 into the atmosphere **(Swaroop et al., 2015)**. At the same time, a huge amount of construction and demolition (C and D) waste is created. Traditionally, construction and demolition (C and D) waste are used as landfills, resulting in land resource occupation, pollution of the environment. There is an increasing need to use renewable resources instead of non-renewable resources **(Guo et al., 2018; Pedro, 2017)**. The use of waste materials in construction materials could reduce the environmental effects of cement and concrete production. Selective demolition is one of the major assumptions for the utilization of recycled construction and demolition (C and D), which means very careful sorting for the materials during the demolition work **(Pacheco Torgal and Jalali, 2011)**. That could lead to high quality materials for input to the recycling process and for secondary raw materials, and this can be used for new applications as a substitute for main raw materials **(Pavlů, 2018)**. Also, the utilization of construction waste prevents the accumulation of concrete of old building waste that needs to be taken away or transported to the dumping land of solid waste. Furthermore, the cost of transportation fuel for it. The accumulation of these waste solids has caused changes in the landscape architecture, which happens by modifying the morphology of the topography of the waste material receiving area **(Martínez et al., 2015).**

2. WASTE BRICK IN CONCRETE

Brick is considered the second most common building material after concrete, and if there is damage occurs during its production, construction, and demolition activities. It is regarded as C and D waste. The ability to recycle the brick waste in the manufacture of the concrete is considered an environmentally friendly substitutional. That solution will not only decrease the problem of its disposal and moreover helps to minimize the consumption of natural materials. In addition, brick production does not involve the use of chemicals, so it considers safe and stable construction materials **(Wong,2018).**

The durability and the mechanical properties of concrete using the brick waste (CBW) as fine cement aggregate or coarse aggregate are summarizing below:-

2.1 Utilization Waste Brick Powder (WBP) in Concrete:-

The existence of pozzolanic is one of the necessary criteria for products that are used as a substitute for cement.

Pozzolans materials are considered as Siliceous and Aluminous amorphous materials that can react with calcium hydroxide $Ca(OH)_2$ to form (C-S-H) calcium silicate and aluminum silicate hydrate with the presence of water to improve the cement-based characteristics **(Afshinnia K,** and **Poursaee, 2015; Navratilova** and **Rovnanikova, 2016)**. Brick is manufactured by firing the clay that contains percentages of SiO_2 and Al_2O_3, with low CaO levels **(Reig et al., 2013)**. If the amount of (SiO_2 +Al_2O_3+ Fe_2O_3) in clay is greater than 70%, the clay brick is considered as pozzolanic materials. This classification is according to the requirement of (ASTM618) **(Olofinnade, 2016)**. As shown in **Table 1**, the sum of silicon, ferric, and aluminium oxide of WBP exceeded 70 percent , which proved that WBP had high pozzolanic activity; these components will facilitate the creation of C-S-H (calcium-sulfate-hydrogen) hydrates of silicates) or C-A-H (calcium aluminate hydrates) and thus influenced mortar and concrete performance.
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Table1. Chemical Composition of Brick Powder.

SiO_2	56.82	41.47	60.64	54.83	67.58	49.9
Al_2O_3	11.36	39.05	14.23	19.05	18.94	16.6
Fe_2O_3	2.36	12.73	4.93	6	8.084	6.5
CaO	20.20	0.63	0.27	9.39	0.948	9.7
SO_3	0.83	1.59	—	2.9	0.130	3.3
MgO	3.02	—	1.72	1.77	0.719	5.5
Na_2O	0.86	—	1.94	0.5	0.246	0.5
K_2O	0.86	2.81	1.44	3.15	1.884	4.4
TiO_2	1.03	0.98	0.97	—	1.06	0.8
MnO	—	—	—	—	—	0.1
P2O5	—	—	0.90	0.2	—	0.2
Ref	**(Ahmed et al., 2019)**	**(Ortega et al., 2018)**	**(Olofinnade et al., 2016)**	**(Farrell et al., 2001)**	**(Liu et al., 2017)**	**(Reig et al., 2013)**

Pozzolanic brick activity results from converting crystalline structures of clay silicates to amorphous compounds during brick processing, where the clay is exposed to high temperatures between (600 ° - 1000 °) C. The microstructure characterization can verify the pozzolanic activity of (WBP). **(Ahmed et al., 2019; Aliabdo et al., 2014).** They investigated the pore structure of paste specimens with CBP. They discovered that the pozzolanic reactivity of CBP and possibly the rehydration of unhydrated cement particles in attached mortar enhanced the density of the matrix refined the pore structure. Waste brick powder (WBP) will also help to work as a filler, minimizing the effect of the phenomenon of greater shrinkage **(Zhu,** and **Zhu**

Z., 2020). And its special gravity (S.G) is greater than the other concrete materials; it helps to increase the density of concrete, resulting in highly compact and less porous concrete.
As a result, by using less quantity of cement, higher strength concrete mix can be obtained, which indirectly lower the primary overhead cost (m3) of concrete, and it is considered an environmentally friendly concrete (EFC) because it eliminates the accumulation of waste of the demolished brick by consuming it **(Rani** and **Jenifer, 2016)**.
Several researches show that waste brick powder (WBP) can be used in concrete as a partial substitute for cement; **Table 2** summarizes some of these previous researches.

Table 2. Results Summary of Using Waste Brick Powder in Concrete.

Ref	Replacement level	Findings	Remarks
(Ortega et al., 2018)	0%, 5%, 10%,15 %, 20%, 25% and 50%	• The workability of fresh concrete decreasing with increasing the replacement level of CBP by the weight of cement • There is increasing in 5% replacement of (CBP) for the compressive strength up to (4.28%), but when use (10%,15%,20%,25%) replacing from cement weight ,the results showing there is decreasing approximately (9.16 , 17.3 , 27.39 , 39.29))% for 28 days curing respectively. • There is increasing in 5% replacement of (CBP) for Splitting strength up to (3.04%),but when use (10%,15%,20%,25%) replacing from cement weight ,the results showing there is decreasing around((1.67 , 10.36 , 16.77 , 25.28 &59.14)) present at 28 days curing respectively. • For the flexural strength the percentages of increases for concrete mix when replacing (5%,10%)of (CBP) are (8.73% &5.28) respectively compared to reference concrete at 28 days.	• mix proportion 1:1.5:3 • W/C ratio 0.5 • micro Silica fume add as pozzolana (10% by weight of cement) • same quantity of aggregate and water as in the reference mix • The grain of (CBP) passing from sieve no. 0.075mm
(Rani and **Jenifer 2016)**	10%20% and 30%	• there is increasing in(the compressive, split tensile, & flexural strengths) when used 10%, 20% replacement level of cementitious material relate to the normal concrete strength • The concrete improvements initial strength so the molds can be taken away early, this way decreasing the overhead of secondary cost.	• Mix proportion 1:1.12:2.687 • W/C = 0.425 • (BP) passing through sieve 90 microns
(Liu S. et al ., 2017)	15% - 45%	• At replacement levels of up to 45%, compressive strength was reduced (up to about 31 percent) • Cement paste containing 45 % brick dust and having a larger surface area Approximately 20% greater 28days strength than the	• brick dust with specific surface areas of 460 m2/kg & 632 m2/kg.

		corresponding paste with a smaller specific surface area • Heat curing increased compressive strength by about 25% when compared to air curing at room temperature	
(Olofinnade O et al ., 2017)	10% – 40%	• At 10% replacement, the compressive strength was found to be optimal (an increase of up to 9%). The compressive strength was comparable with the control specimens at a replacement level of 20%; further replacement decreased the compressive strength.	
(Resin et al ., 2018)	0%, 5%, 10%,15%	• The compressive strength is improved by replacement of brick powder (BP) to a percentage less than 10% by weight at all ages, but it starts to decrease at 15% replacing but it still more than reference mix **Figure1.** • Steel potential was (-265 mV) at 150 days for specimens of 10% replacement level, which was lower than reference concrete (-338 mV). Following that, it started to fluctuate and appeared to shift to a more negative potential. • After 300 days of exposure, the average potential in reference concrete was -356 mV, while the average potential in brick concrete was (-337mV). This behaviour could be explained by the better adsorptive capacity, which results in a barrier film that is difficult to break or penetrate by the corrosive chloride ions, and the pozzolanic reaction decreases the porosity and permeability of cement paste, making it stronger and more durable, **Figure 2.** • Water absorption for 10% brick waste was less than that of reference concrete at all curing ages, and it also decreased as curing ages increased from 150 to 240 days. At 240 days, the maximum reduction in water absorption was 13.87 % when compared to reference concrete. This decreasing is attributed to the pozzolanic reaction of brick waste, which can refine pore structures and decrease connectivity. Water transport is governed by factors such as pore connectivity and pore size distribution. • At age 150 days, water penetration depth was less than that of reference concrete for 10% replacement brick waste because the incorporation of brick waste as a replacement for cement content may improve the pore structure in the transition zone, so it decreasing the water permeability. •	• W/C = 0.41-0.51 • 1.2,1.4%HRWR by wt. for reference & brick modified concrete respectively • BP particles size = 100 µm, passing from sieve no.150 µm • concrete embedded in a 3.5 percent NaCl solution

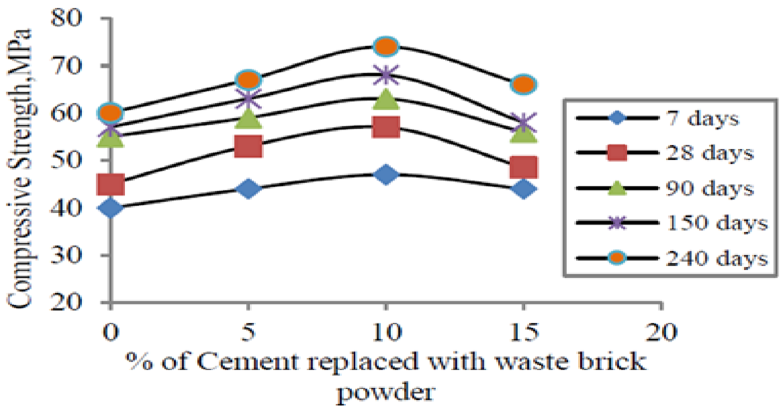


Figure1. Effect of various content of waste brick powder on compressive strength as compared with reference concrete. **(Resin et al., 2018).**

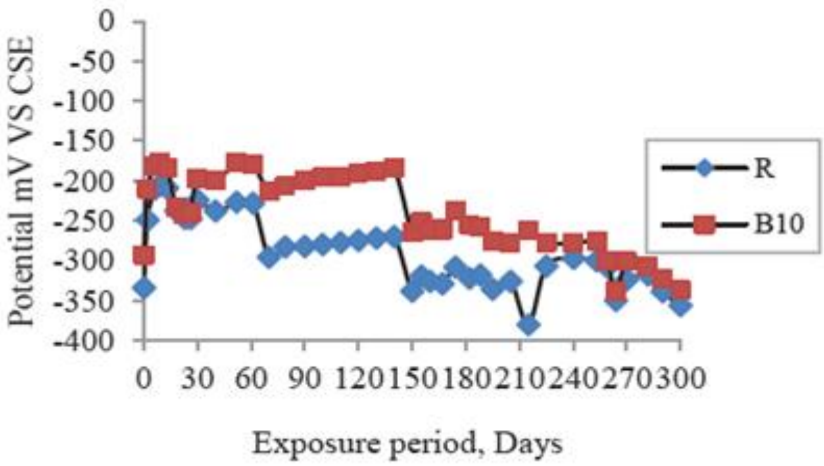


Figure 2. Potential versus time behavior of 10% brick material – concrete compared to the reference concrete **(Resin et al., 2018**).

2.2. Utilization of Waste Brick in Concrete as Aggregate

The quality and properties of recycled brick aggregate are mainly responsible for the possibilities of using it in concrete. The major difficulties of using RBA are its high absorption of water, which has a negative effect on the workability of fresh concrete, and excessive impurities that may weaken the mechanical properties of concrete **(K. P. Verian et al., 2018)**. The water absorption varies from (10.1 to 18.9) % in coarse recycled brick aggregate, up to twenty-five times higher than natural aggregate. And the dry density of coarse recycled brick aggregate, which ranges from 1800 to 2700 kg/m^3, is typically lower than that of natural gravel **(F. Debieb** and **S Kenai, 2008;** Whereas when using fine recycled brick **M T Uddin et al.,2017)**.

aggregate, density and water absorption are two major differences between sand and fine RBA. Fine RBA mainly derived from crushed bricks had a density of between 2000 and 2500 kg/m3, which was lower than natural sand. The water absorption of fine RBA was found to be between (12 to 15)%, which is more than 10 times higher than natural sand **(J M Khatib, 2005; F Debieb**

& S Kenai, 2008; A V Alves et al.,2014). the compressive strength Between the ages of 28 and 90 days, for fine RBA-containing mixture increased, and the increase was greater than that of conventional concrete and fine RCA-containing concrete. the explanation could be the, presence of silica and alumina in crushed bricks, which could cause pozzolanic reactions**(J M Khatib, 2005)**. Another reason could be a lower w/c ratio in concrete mixtures with fine RA, which is caused by non-compensation of RA's high water absorption, resulting in a lower effective w/c ratio. Other studies that measured the w/c ratio based on RA's water absorption corroborated this hypothesis. These studies found no significant differences in the rate of strength growth between the ages of 28 and 90 days **(Debieb & Kenai, 2008; Alves et al.,2014)**. .
Application of RBA instead of natural aggregate in mortar and concrete is the modern trend and many investigation have been done to estimate the characteristic of performance for the recycled concrete aggregate and mortar, the literature reviews of some studies are summarizing in **Table 3**

Table 3. Results Summary of Using Waste Brick Aggregate in Concrete.

Ref	Replacem-ent Level & Type of aggregate	Findings	Remarks
(AL-sadey, 2019)	0% 25%،50% and 75% Coarse aggregate	• crushed concrete brick has low workability , when comparing with the normal concrete • The utilize of crushed bricks in concrete as a coarse aggregate causes decreasing in the compressive strength of replacing (25 ,50 ,75)% at 7 and 28 days. • there is increasing in water to cement ratio , when using the crushed brick as coarse aggregate because it increases the concrete absorption to the water	• The nominal mixing roportion cement;sand; coarse aggr.)by wt. with slump of 100±5 mm as a base to get constant workability for all specimens when designed. • Mix size 19 mm
(Rasool et al., 2020)	0% ،%5 and10% fine aggregate	• the results appeared that The optimum percentage of replacement was (30%IF+10%BP), the mix with this percentage of replacement achieved enhancements about (21.26), (13 %) and (45%) in compressive strength , Splitting tensile strength & Flexural strength respectively at 28 days.	• mix proportion 1:2:4 • W/ C = 0.45 • (10%,20%,30% & 40%) of cement replaced by Iron Filings (IF)
(Dang J et al., 2020)	0%, 50% and 100% Fine Aggregate	• the utilization of (RBA) causes increasing in porosity and the total pore volume for recycled brick aggregate concrete • Because of the RBA pozzolanic reactivity , Its replacement from FA has lead to reduction in the coefficients of chloride migration , that	• Water to cement ratio = 0.55 and 0.35 respectively

		gradually decreases with an increase in the percentage of replacement .nevertheless, carbonation resistance, water sorptivity, water absorption ,drying shrinkage of recycling brick aggregate (RBA) concrete deteriorate due to porous structure of RBA. • The XRD test and SEM-EDS test results show that pozzolanic reactivity is higher in the RBA. the Crystals (Ca(OH)2) is used to create more uniform denser hydration products with an increase in the rate of replacement which improved the adhesion of rBA to the cement matrix and increased the compactness of ITZ, resulting in improved chloride penetration resistance of recycled concrete with Rba	
(Khalil W I et al., 2020)	0% 10%,20% and 30% Coarse aggregate	• Increasing the crushed waste clay brick aggregate content . causes decreasing in compressive strength , and highest reduction in CS was 53.37% for replacement 30% at 28 days , while for 10% replacement level ,the specimen with showed the greatest performance with the lowest decrease only 3.13% compared with reference mix at 28 days. • For the tensile strength , utilization of CWCB aggregate causes decreasing in it up to 45% when use 30 per cent dosage at 28 days , and the optimum replacement of (CWCB) aggregate was 20 per cent with the lowest reducing about 8.6% related to reference mix. • There is increasing in flexural strength with 10% replacement of CWCB aggregate up to27% compared with reference mix.	• Geo-polymer concrete • alkaline solutionto binder=0.65 • Na2SiO3to NaOH=2:1&14 concentration of molarity • Dosage of S.P 2% ,extra water 10% , both by weight of MK
(Veerakumar, & Saravanakumar ,2018)	,5% 0% 10% ,15% and 20% Fine aggregate	• The result of comparative strength for replacement level (5%, 10%, 15%, 20%) was (18.26, 14.62, 2.89, -6.92)% at 7 days , (28.7, 40, 5.88, 8.43)% at 14 days and (10.45, 11, -11.78, 6.6) at 28 days • The optimal replacement of the fine aggregate is obtained at a 10% replacement of the fine aggregate by crushed brick debris relative to the reference concrete strength. • Concrete gain early strength and so the templates can be removed early, reducing the secondary overhead cost. The comparative strength effects of cubes for 7, 14 and28 days are compared for different mixtures are shown in Fig.3	• Mix proportion 1:1.5:3 • W/C = 0.5 • The used waste brick was crushed to get particles passing from sieve no. 4.75 mm and retain on the sieve no.0.075mm

(Lakshmi & Nivedhitha, ,2015).	(10%, 20% & 30%) Recycle Fine aggr.(RFA) & Recycle Coarse aggr.(RCA)	• There is increasing in compressive strength at 28 days up to (10.15, 2.3) for replacing (10%, 20%) respectively, and decreeing up to (10.46) for 30% replacing of the RCA. • There is increasing in compressive strength at 28 days up to (17.66, 12.37) for replacing (10%,20%) respectively, and decreeing up to (7.08) for 30% replacing of the RFA. As showing in figure 4 (a) • There is increasing for split tensile flexure strength at replacement level (10%, 20%), and decreasing at 30% replacing. As showing in figure 4 (b) • For flexure strength there is decreasing for all replacement percentages. As showing in figure 4 (c) • The optimal substitution of NCA and NFA with • RCA and RFA respectively for tensile strength was found to be 20%, and 10% for compressive strength .	• Mix preparation 1:1.425:3.10 • W/C =0.5 for all mixes • Target strength 20 MPa • RCA passing from sieve no. 20 mm and retained on sieve no.4.75 mm • RFA passing from sieve no 4.75mm and retaining on sieve no75µm
(Hirenath M et al., 2017)	0% 25%،50% and 75% Coarse aggregate	• With increase the replacement percentage of coarse aggregate the compressive strength decreasing around (4.1, 32.9, 41.6, 64.87)% for replacing (25%, 50%, 75% , 100%) respectively at 28 days. • Split tensile strength increased at 25% replacing up to (19.2) related to reference mix , and decreasing at other percentages up to (14.12, 36.12, 56.4)% for replacing (50%, 75%, 100%) at 28 days • The 25% replacement level found to be the best substitute of concrete in view of economy and strength.	• Mix proration 1:1.44:2.9 • W/C = 0.53 • Waste brick broken into approximately size 80mm

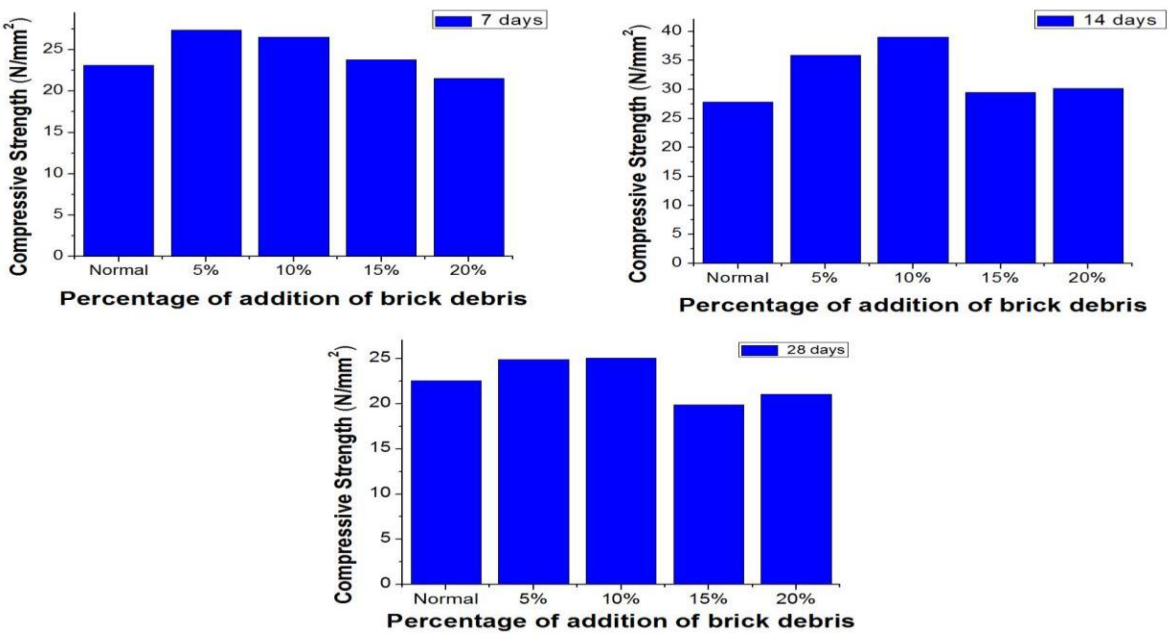
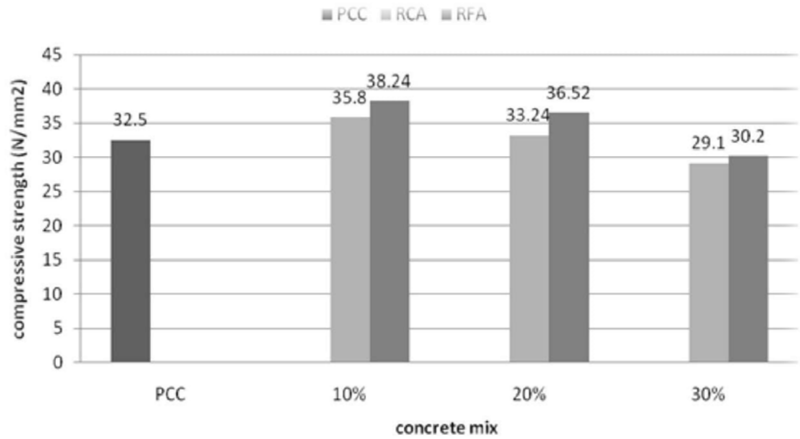
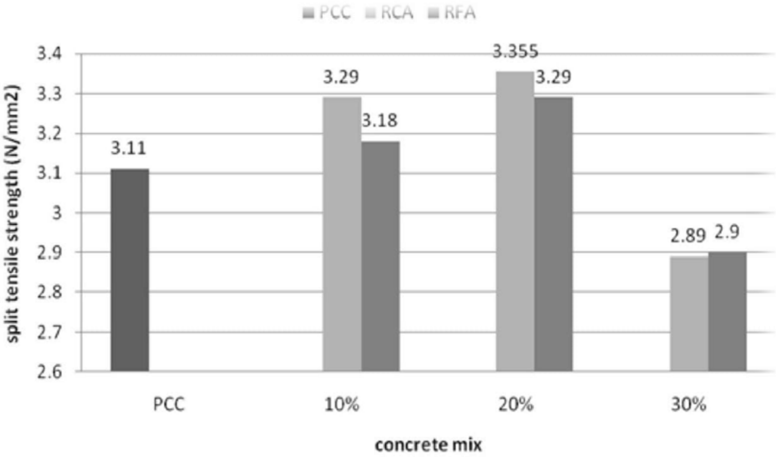


Figure 3. Comparison of Compressive strength for various proportions of brick debris @ 7, 14 and 28 days. **(Veerakumar & Saravanakumar, 2018).**



(a)



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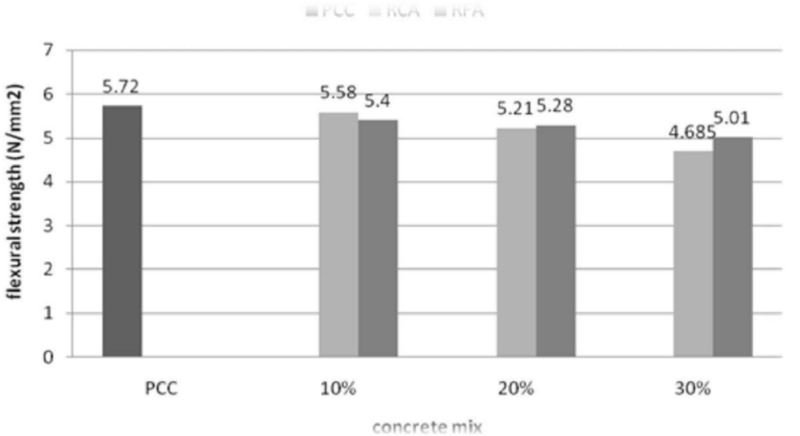

(c)

Figure 4. Effect of recycled aggregate on mechanical properties of concrete (a) compressive strength , (b) split tensile strength and (c) flexural strength of concrete . (**Lakshmi, & Nivedhitha, ,2015).**

3. CONCLUSIONS

- the potential of using (WB) as partial replacement of cement or aggregate (course or fine) to produce sustainable concrete summarized in This review
- The clear benefit of using the waste brick in concrete is the saving of natural resources , energy savings and reduce carbon dioxide CO2 emissions that are depleted during the cement and concrete production process.
- Permit the use of waste brick powder as a partial substitute of cement with replacement level up to 10% for the manufacture of concrete because of the pozzolanic activity for it.
- The utilize of brick powder helps to raises the density of concrete resulting lower pores and more compacted concrete
- The using of waste brick powder can minimizing the corrosion of steel reinforcement .
- The use of fine brick aggregate con improve strength and reduce the chlorides penetration in to concrete, if used by no more than 10%

- The use of waste brick as coarse aggregate in concrete often decreasing the compressive strength with increasing in the replacement level.
- The workability of concrete containing crushed brick aggregate is lower than that for convention concrete, because the high absorption of it
- Waste brick aggregate could reduce the cost of transportation and dead loads, and it develop durability of concrete in some cases.

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