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Review Article

Use of Waste Materials in Concrete: A review

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ABSTRACT

Millions of tons of waste is produced in the world each year and most of it is not recyclable. Furthermore, recycling waste consumes energy and produces pollution. In addition, accumulation of waste in the suburbs and the disposal of waste are very dangerous for the environment. Using waste material in concrete production is an appropriate method for achieving two goals: eliminating waste and adding positive properties in concrete. Since the green concrete industry is expanding, it is necessary to evaluate concrete that contains waste from all aspects in order to determine its capability. This literature study consists of two parts i.e. the use of waste as a substitute for cement and as a substitute for aggregates. Leading waste material that has been used as substitutes is highlighted and the characteristics of the resulting concrete is evaluated. Among other findings, rubber was found to have improved fire resistance and ductility in concrete and agricultural and PET wastes were successfully used in non-structural concrete, while glass helped to improve thermal stability.

Keywords: Concrete, environment, sustainable development, waste materials

INTRODUCTION

Concrete, one of the most important construction materials in the construction of infrastructure and development facilities, has the potential for significant and positive environmental participation (Tavakoli et al., 2012). Waste material in concrete can be used as cement or aggregate replacement, fillers or fibres. As cement is a dangerous pollutant of the environment, waste material can be used as a substitute for cement as well as for aggregates. The environmental advantages of using waste material as a replacement for cement can be investigated in two ways. One is the removal

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of a part of the cement from concrete and the other is the use of waste material that is useless in concrete. Due to the volume of cement consumption around the world, a lot of waste can be used as a replacement for concrete. From the standpoint of reducing cement, there are many benefits attached to the use of pozzolans, including the reduction of greenhouse gasses, the most hazardous of which are carbon dioxide and nitrogen oxides.

The consumption of cement is 60 million tons per year in Iran (Tavakoli et al., 2012); if 5% of the concrete projects in our country used 10 to 15% of waste material to replace cement, in one year a large amount of the waste generated in Iran can be reused. Also, if this consumption of cement continued and extended to 10% of the country's projects, the total waste from past years can be completely consumed by reusing it in concrete in a few years. This will save on consumption of the country's other resources and at the same time, reduce environmental pollution in the country. Therefore, the use of waste material as a substitute for cement is beneficial for both reducing cement consumption and waste consumption. As it is impossible to use only waste material instead of cement in construction, waste material can be reused as an aggregate. Aggregates occupy about 70% of the volume of concrete, thus a large amount of it can be reused. To avoid consumption of raw materials that are already scarce, this option is crucial, especially for European countries that are facing mineral deficiency.

The survey investigates aggregate replacement and cement replacement. It also discusses the advantages and disadvantages of each.

WASTE MATERIAL AS AGGREGATE REPLACEMENT

Glass

Glass is a colourless, transparent, hard and fragile material, with a hardness of 6.5. According to ASTM, glass is an inorganic material. In its molten state, as glass gets colder, it becomes more rigid without crystallisation. Silica is a fundamental constituent of glass, but in most common glasses MgO, CaO, Al_2O_3 and Na_2O are also found. Studies have shown that it is possible to use glass in concrete in three forms: as Coarse Glass Aggregate (CGA), Fine Glass Aggregate (FGA) and Glass Powder (GP).

When mixed with cement, glass undergoes a chemical reaction that produces a secondary hydrated calcium silicate (C-S-H) and a pozzolanic reaction with cement hydrates (Islam et al., 2017). Meyer and Baxter (1997, 1998), pioneers in this field of research, tried to prove the practicality of concrete production containing 100% glass aggregate and 20% metakaolin. The studies showed that an increase in the amount of glass waste reduced not only the specific weight of concrete but also the compressive strength of the concrete due to reduced adhesion with it (Topcu & Canbaz, 2004). This type of concrete has high thermal stability due to high thermal conductivity in comparison with conventional aggregate concrete; thus, it can be used for buildings that require thermal stability. This type of concrete is ideal for buildings in cold, mountainous areas (Poutos et al., 2006). Cazacliu et al. (2010) and, Ling and Poon (2012), showed that the use of glass in concrete is practical, but its size can influence the effectiveness of concrete. Reduction of particle size improves workability but reduces the 28-day compressive strength of cement. The combination of both fine and coarse glass can improve water absorption and bring the shrinkage of concrete to its lowest value (de Castro & de Brito, 2013).

Due to the fact that glass aggregates are composed of a high percentage of silica, it is possible that the alkaline reaction of the cement causes a faster reaction between alkali and silica in the aggregate. However, it is possible to prevent this by controlling the exact percentage of the cement used. In 2015, Cota's survey focused on three parameters: impact of the particle size of the glass, the impact of the percentage of the glass and the amount of metakaolin added.

The results indicated that the use of metakaolin and glass particles can cause specific weight loss, especially when the glass is replaced with finer particles. As a result, an increase of 79% was observed in comparison with control samples when substituting with fine quartz particles; however, the dynamic modulus of concrete increases when replaced with larger particles and also, concrete containing coarser-grain particles is more prone to reaction between alkali and silica (Cota et al., 2015). The studies showed that glass particles can cause ASR expansion and can also reduce compressive strength. If there are pores that provide enough space for ASR production, it may be possible to mitigate this reduction of strength. Adjusting the water-to-cement ratio and the amount of fine particles can provide this space. Figure 1 shows that the highest expansion is achieved by adding coarse glass particles, the use of 15% glass and non-use of metakaolin. As can be seen in the charts, the use of metakaolin reduces alkali-silica expansion. In another study, liquid crystal display (LCD) was used as fine aggregates, with 0%, 10%, 20% and 30% replacement by ordinary sand. The results showed that compressive strength and ultrasonic pulse velocity increased with curing time but decreased with an increase of w/b ratio (Wang & Wang, 2017).

Eventually, glass waste can produce not only suitable concrete for harsh climatic conditions due to its high thermal stability, but also concrete of appropriate strength. In general, glass can be used as an aggregate with optimum percentage in many cases, but it is necessary to control the ASR expansion. This is the main problem with using silica.

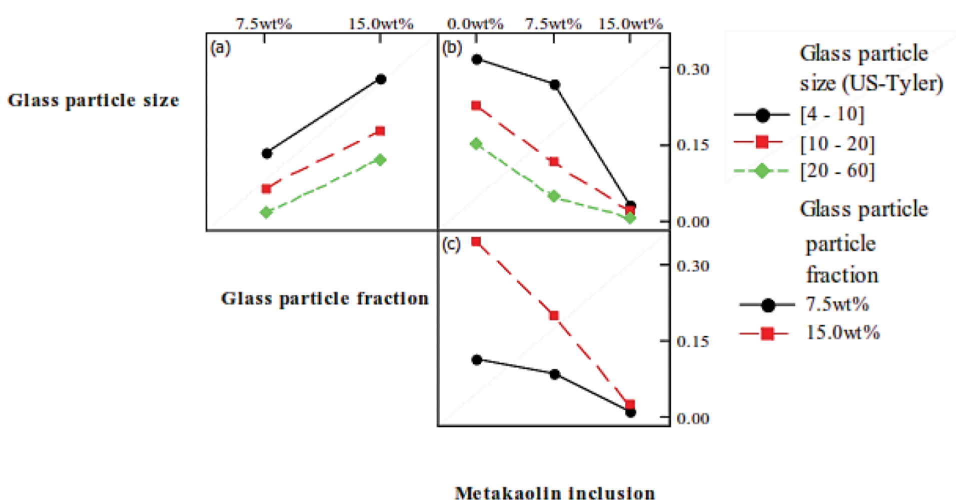

Figure 1. The third interaction effect related to the mean ASR expansion (Cota et al., 2015)

Poly(Ethylene Terephethalate) (PET)

PET, or Poly(Ethylene Terephethalate), belongs to the long-chain polymers of the polyester structure. The components of PET are pure terephthalic acid and ethylene glycol. Both are derived from petroleum products. The polyester processes involve other chemicals that can be made via polymerisation between an acid and an alkali. PET is an amorphous glass material. Using PET waste in concrete can save and preserve the environment. Yoon et al. (2005) analysed the microstructure of PET lightweight aggregates and then examined the effectiveness of the granular slag of molten metal (GBFS) on it. In these experiments, the density of the concrete containing PET aggregates increased from 1940 to 2260 kg/m^3, and the transition zone between PET particles and the cement paste in comparison with natural aggregates expanded more. Overall, it was expected that molten metal slag grain could boost the PET level and limit the transition zone leading to the reaction of calcium hydroxide. Other experiments showed that using PET in concrete can increase ductility and reduce shrinkage cracks (Sehaj et al., 2004; Won et al., 2009). Due to the lower specific density of PET compared with ordinary aggregates, light concrete with high quality can be produced using PET (Akcaozoglu, Atis, & Akcaozoglu, 2010). Fresh concrete containing PET has lower workability, density, modulus of elasticity and tensile strength than ordinary concrete. Increasing PET to 15% reduced the compressive strength of 15.9 % by up to 18% and reduced the modulus of elasticity of 20% by up to 23%. It also reduced the specific weight loss of 3.1% by up to 3.3%. Figure 2 shows the size and the type of PET particles in this study (Rahmani et al., 2013).

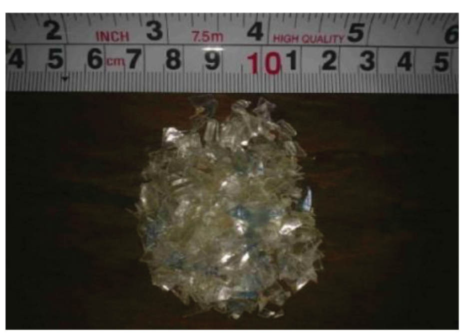

Figure 2. Size and type of PET particles (Rahmani et al., 2013)

Fresh concrete slump was also affected by the size and amount of PET particles, so the high amount of plastic-shaped aggregates reduces the slump of fresh concrete. Figure 3 shows that compressive strength was reduced by increasing the amount of PET aggregates, unlike the action of natural aggregates. PET aggregates cannot react with cement paste. In addition, the transfer zone in this type of concrete was weaker than in the control sample. PET aggregates reduced tensile strength, modulus of elasticity and bending strength. The physical structures of PET aggregates can also change the percentage of water to cement and the slump of concrete. The flaky aggregates of PET can connect two different parts, ensuring stability against the erosion of concrete containing PET aggregates (Saikia & De Brito, 2004). The ultrasonic wave speed of samples that contain PET with 0%, 5%, 10% and 15% reduced compressive strength to 32.56%, 22.65%, 32.75% and 20.7%, respectively. Thus, samples containing 15% PET are integrated and dense. The reduction of compressive strength in these samples was 53.92%, 51.95%, 49.8% and 32.59, respectively. This was similar to the results obtained by Rahmani in 2013 (Araghi et al., 2015).

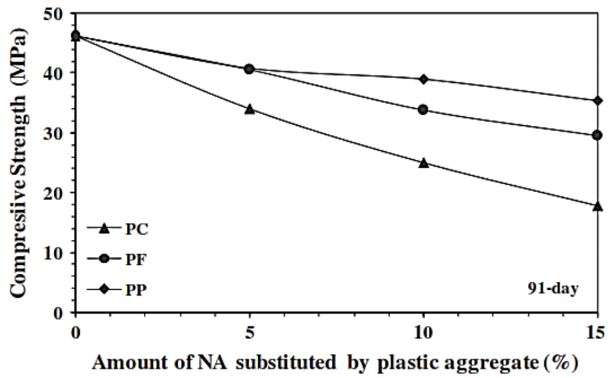

Figure 3. Compressive strength of concrete incorporation of PET aggregates (Saikia & De Brito, 2004)

As the results showed, using pet in concrete was practical and had no significant negative effects on the properties of concrete but for structural concretes that need rather high compressive strength this waste is not a good choice because it cannot react with cement and also, it has lower mechanical strength than ordinary aggregates. However, this kind of aggregate is a good for building lightweight concrete or corrosion-resistant concrete.

Tile and Sanitary Ceramics

A tile is a piece of artificial stone with thickness of a few millimetres and a glassy, soft and smooth surface on one side. Ceramic is a non-metallic and non-organic material. It is classified in two categories of crystalline and non-crystalline. Tile and ceramic waste is created during the transfer process, during or after burning, due to human error, manufacturing error or use of inappropriate material and much of it is due to the destruction of buildings (Tavakoli et al., 2012). Many studies have been done to dump this waste in concrete. The results of experiments showed that it would be feasible to use tile waste in concrete as pozzolan or aggregate (Ay & Unal, 2000; Portella et al., 2006). Using white ceramic aggregates as fine aggregate and substituted with ratios of 10% to 50%, the quality of concrete improved (Lopez et al., 2007). Moreover, if porcelain sanitary waste is used as coarse aggregate in concrete at a rate of 3% to 9%, its resistance is more than that of concrete without additives at a rate of 2% to 8% (Guerra et al., 2009). If the curing process takes a long time, about 28 days, and 15% to 20% of aggregates containing porcelain sanitary waste are used, then the concrete's resistance may be increased (Medina et al., 2012; Medina et al., 2012). Heidari et al. (2013) examined the effect of ceramic aggregates in concrete. For this purpose, ceramic was used as both coarse grain at a rate of 0% to 40% and sand at a rate of 0 to 100%. Figure 4 shows the size of the ceramic particles used in these studies.

Figure 4. Different sizes of ceramic tile waste (Tavakoli et al., 2013)

The results showed that the use of ceramics did not have a significant negative effect on the properties of concrete. The optimum sample of ceramic as an alternative to sand was about 25 to 50%. The best example of using ceramics as coarse grain used between 10% and 20% of it. Not only was there increase in compressive strength in this instance, there was a decrease in specific weight without a significant negative effect on water absorption. Table 1 and Table 2 show the summary of these results.

Table 1
Physical and mechanical properties of concrete mixes (Phase A) (Tavakoli et al., 2013)

Sample	Slump (mm)	Specific Weight (kg/m^3)	Water Absorption (%)	Average Strength (MPa)	
				7 days	28 days
C	60	2441	5.05	26.9	33.1
CS25	55	2430	4.96	28.1	35.7
CS50	50	2382	4.79	27.2	35.1
CS75	40	2341	5.10	25.8	34.6
CS100	40	2294	5.30	24.1	33.7

Table 2
Physical and mechanical properties of concrete mixes (Phase B) (Tavakoli et al., 2013)

Sample	Slump (mm)	Specific Weight (kg/ m^3)	Water Absorption (%)	Average Strength (MPa)	
				7 days	28 days
C	60	2441	5.05	26.9	33.1
CG10	50	2427	4.9	28.2	34.8
CG20	50	2407	5.2	27	34.3
CG30	45	2397	5.45	27.2	34.1
CG40	40	2385	5.7	25.7	33

Mechanical strength increased by addition of waste aggregates and it was higher than that of the control sample. In addition, maximum water penetration depth in the waste aggregates in the treated concrete was lower than in ordinary concrete; the amount used was less than 30 mm. Thus, the replacement of natural aggregates with waste aggregates can increase water penetration resistance (Medina et al., 2013). In order to create concrete with good performance, concrete with a mixture of 20% natural and ceramic aggregates can be used as it gives the same compressive strength as normal concrete with 100 MPa. The corrosion probability can be reduced by the 180th day of curing and by using 50% of the mixture aggregates (Gonzalez & Etxeberria, 2014). Therefore, it is possible to use tile waste in the form of fine and coarse aggregates. It should be noted that ceramic particles can also be porous or hard, in which case they are not only effective in the process of water absorption, but also in the elasticity of concrete (Anderson et al., 2016).

Generally, tile and ceramics with low specific weight and pozzolanic properties are a good choice for manufacturing concrete, but the results have shown that this material must be tested before concrete production and cannot be relied on to give the results of these preliminary studies because the type of burning of the tile and its constituents and even the type of mixing plan are factors that influence the behaviour of the concrete.

Clay Bricks

Fired bricks are burnt in a kiln and most of them contain silica, alumina, lime, iron oxide and magnesia. Because of this chemical structure, the use of bricks in concrete production seems to be practical. Researchers have suggested different mixtures to create this type of concrete. One study showed that the compressive strength of this concrete has a downward trend. This reduction was equal to 10% to 35% for coarse aggregates and 30% to 40% for fine aggregates (Akhtaruzzaman & Hasnat, 1983). Using clay bricks as sand in concrete increased water absorption and this may affect the durability of concrete parameters, so this subject needs more investigation (Tavakoli et al., 2014). In terms of durability, the concrete containing clay brick waste was no different from the control sample. Nevertheless, the brick aggregates had a negative effect on the durability of the reinforced concrete. A high amount of clay brick aggregate can reduce the corrosion time of bars, although this concrete has better performance in freezing and thawing. As the amount of bricks increase, the stability against the chloride ion penetration reduces. This reduction can be due to the higher absorption of the bricks because of their porosity. The 28-day compressive strength of concrete with brick coarse aggregates was slightly greater than that of the control sample and workability was also improved by increasing the amount of the brick coarse aggregates in the concrete (Adamson et al., 2015).

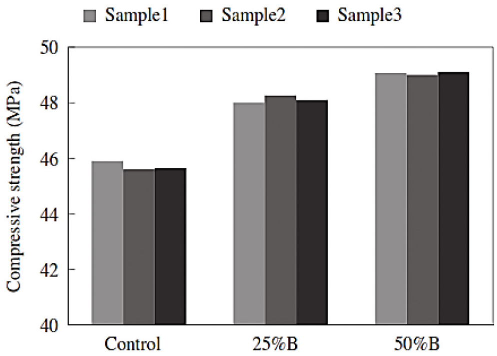

Figure 5. The 28-day compressive strength of the samples (Adamson et al., 2015)

In general, the results showed that using this type of waste was economical and practical. In addition there were no significant negative effects on the concrete. However, bricks are not suitable for use in reinforced concrete because they cause corrosion of bars.

Tyres and Rubber

Tyres are rubber pieces that are mounted on vehicle wheels. Tyres are made of natural rubber, styrene-butadiene, polybutadiene, carbon black and silica, which is used in high-performances tyres. The main idea of using this elastomeric material in cementitious matrix is to reduce the stiffness of concrete in order to make it more flexible and to improve its resistance to fire (Olivares & Barluenga, 2004). The use of tyre scrap as a substitute for aggregates and cement in concrete is new. Figure 6 shows grading tyre that can be used in concrete.

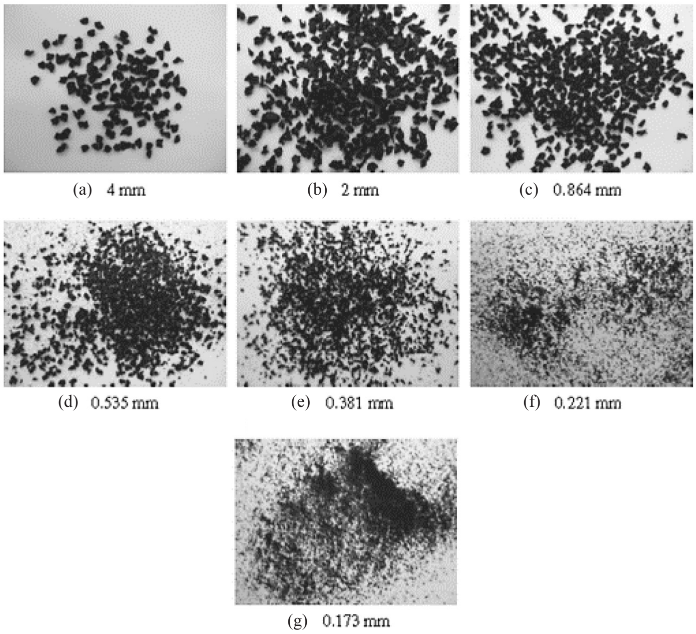

Figure 6. Various sizes of crumb rubber (Li et al., 2014)

Olivares and Barluenga (2004) used rubber waste as fibre. The results showed that by increasing the amount of rubber, the performance of concrete decreased. A flexural strength test showed that the concrete samples containing rubber tyre as fibre were stronger by up to 20% compared with the strength of the control samples. This could have been due to the conversion of the concrete to a more flexible material through the addition of rubber fibre. The control samples showed fractures caused by brittleness, and immediately split after cracking, while the samples containing plastic fibre became deformed but did not collapse (Yilmaz & Degirmenci, 2009). Sohrabi and Karbalai (2011) also showed that using silica fume with increased adhesion between the cement paste and rubber particles improved the filling of the pores and increased the compressive strength. The density of this type of concrete is also 13% less than that of the control samples (Pelisser et al., 2011). The increase of waste tyres can influence the carbonation depth, especially if the tyres are used as coarse-grained rubber (Bravo & Brito, 2012). Workability is also reduced by keeping the ratio of water to cement and increasing the amount of the ash of rubber. By increasing the percentage of rubber ash for water-to-cement ratios of 0.35 and 0.45, compressive strength was decreased. Figure 7 shows the 90-day compressive strength of cement with various ratios of water-to-cement and rubber ash (Gupta et al., 2014). In freezing-thawing resistance, the experiments showed that replacing or adding fine crumb rubber improved this property (Gesoğlu et al., 2014a, 2014b; Thomas & Gupta, 2016). It would seem that the use of tyre waste as an alternative in concrete still needs to be studied and further explored to determine the durability and strength of this material on concrete.

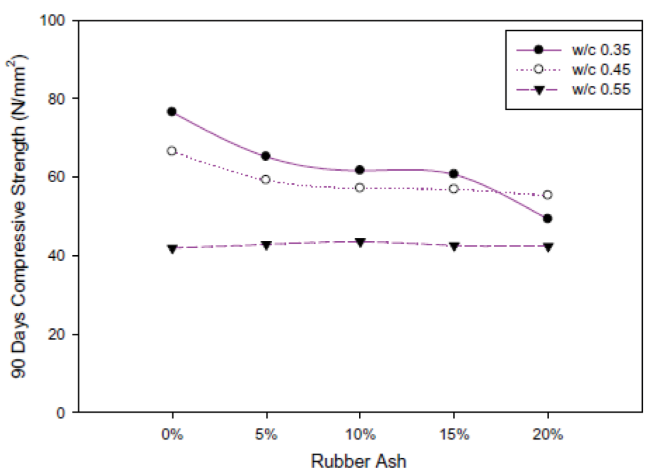

Figure 7. The 90-day compressive strength of rubber ash concrete (Gupta et al., 2014)

Metal

One ton of steel produces 17% of slag, which is used in depot sites. Due to the high production of metal products, a plan is required for its use. The major components of slag include the oxides of calcium, magnesium, silicon, iron and other metals, so it seems that the use of this waste is practicable in concrete production.

The first step in studying these materials was done by Akinmusuru in 1991 regarding the use of metal slag as an aggregate in the concrete (Akinmusuru, 1991). The initial studies proved that slag can be used in the manufacturing of non-structural concretes (Rai et al., 2002), but gradually it was shown that slag conversion to aggregate can be used as a substitute for coarse grain (Tay et al., 2003). In another study, industrial solid waste completely replaced the coarse aggregate and it was proved that this type of concrete had higher shear modulus and chemical stability in acidic and alkaline solutions than ordinary concrete (Ghailan, 2005). Later, the results of using slag in high performance concrete showed that compressive strength, water absorption and tensile strength of this type of concrete were higher than those of the control sample (Demirboğa & Gül, 2006). Slump decreases with the increasing metal waste and, as expected, density and bending strength increase compared to those of the control samples (Ismail & Al-Hashemi, 2008). Studies have shown the possibility of creating concrete with a compressive strength of higher than 150 MPa by copper slag when copper is used as a substitute for fine grain. With full replacement of standard sand and copper slag, it was concluded that the largest reduction in 28-day compressive strength was about 15 to 25%. Figure 8 shows the results on samples of 100 mm cubes. Mixture 1 is concrete without aggregate and steel fibre, mixture 2 is concrete without sand, mixture 3 is concrete without copper slag and steel fibre and mixture 4 is concrete without copper slag. It can be observed that the control sample immediately breaks at the end of the linear region. These studies also showed that the bending strength of fibre-reinforced concrete is approximately two times higher than that of concrete without fibre (Ambily et al., 2015). In a recent study about high-volume slag concrete the results showed that with an increase in slag, carbonation depth increases (Han-Seung & Wang, 2016).

In general, what follows from these results is that, due to the hardness and high density of the steel furnace slag compared to those of the natural aggregates, compressive strength and flexural strength of concrete increase. However, it should be noted that this waste can increase the weight of the concrete and may turn the concrete into a non-consumable material for the building industry.

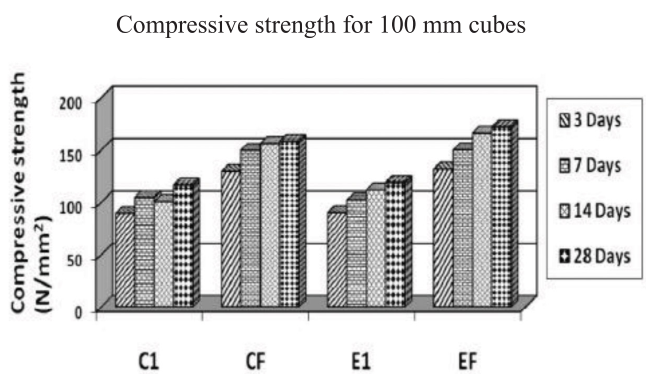

Figure 8. Compressive strength for 100 mm cubes (Ambily et al., 2015)

Concrete Waste

Research into the use of demolished concrete as aggregate for the new concrete production goes back to the end of World War II. Experiments on the use of concrete waste in the production of concrete began in 1993. Evaluation of different concrete mixtures containing fine-grain concrete waste concluded that the addition of a superplasticiser improved the concrete shrinkage (Merlet & Pimienta, 1993). Other experiments showed that drying shrinkage of concrete containing 30% of fine-grain concrete waste with a constant water-cement ratio and varying amounts of water reducer, is equal to the loss of natural aggregate concrete in 180 days (Zega & di Maio, 2011). It should be noted that, by adding fly ash as an alternative to cement, it is possible to reduce the shrinkage of concrete that is due to the addition of waste aggregate (Jeong, 2011). Some studies were done on the effects of increasing the coarse recycled concrete aggregates on mechanical characteristics and deformation caused by shrinkage (Cartuxo et al., 2015). In another study considering two samples with clay brick powder as cement and recycled concrete aggregates, mechanical properties were investigated. Results showed that clay brick powder compensated the decreasing of compressive strength due to the use of recycled aggregates because this powder can fill the porosity of concrete well (Letelier et al., 2017).

Research conducted from 1993 up to now indicates that concrete waste is reusable in concrete production. However, depending on the project, type and amounts should be specified precisely and it is noted that this waste is susceptible to carbonate reaction and may cause corrosion of the reinforcement, so the carbonation depth should be measured.

Agricultural Waste

Between 20 and 30% of agricultural production in the world becomes waste. The using of agricultural product waste has attracted researchers' attention to return the investment to the economic cycle. The most popular agricultural waste is almond and coconut shell.

Almond shell is not very common and it is more used in research to produce light weight concrete. A study by Siamardy and Vahedi (2008) was conducted by using almond shell as the coarse aggregate. Their research showed that this type of concrete had average performance slump, high air content and low density compared to those of ordinary concrete. Another study on coconut shell showed that this material had the capability to produce light concrete with good quality (Gunasekaran, 2008). In the long-term experiments, tests carried out in 365 days of concrete, this type of concrete also had good quality. Even the ultimate adhesion strength of this type of concrete is much higher than the theory of adhesion strength (Olanipekun et al., 2006).

Investigating the characteristics of concrete containing coarse grain coconut shell showed that this concrete had lower weight and its mechanical properties were equal to concrete with ordinary coarse aggregate. The long-term compressive strength of concrete containing coconut shell aggregate showed good quality and showed flexural behaviour comparable to that of the control sample (Gunasekaran et al., 2012, 2013; Gunasekaran et al., 2010; Gunasekaran et al., 2011a, 2011b). A recent study showed that 40% replacement of conventional aggregate with coconut shell could decrease the compressive strength of concrete by about 22% and to improve this property, reduction of the water-to-cement-ratio was necessary (Kanojia & Jain, 2017). Generally, it can be said that concrete made with coconut shell has higher compressive strength than concrete containing oil palm shell because of the roughness of coconut shell and its better adhesion with cement flakes (Shafigh et al., 2014). The microscopic surface of both materials can be seen in Figure 9 and Figure 10.

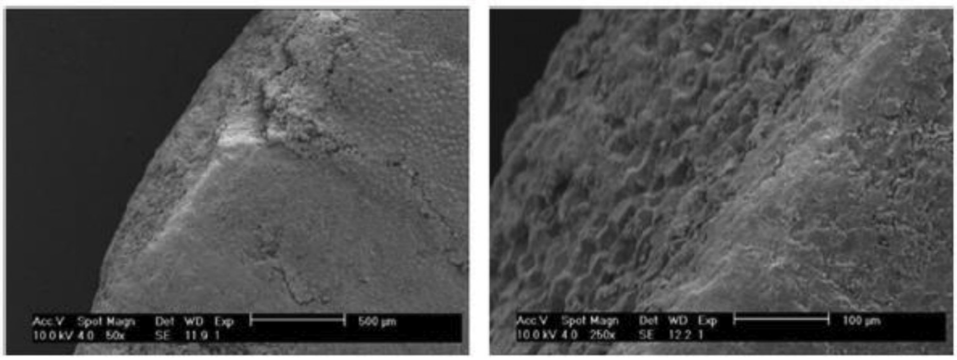

Figure 9. Microscopic images of the surface of an OPS grain in two scales (Shafigh et al., 2014)

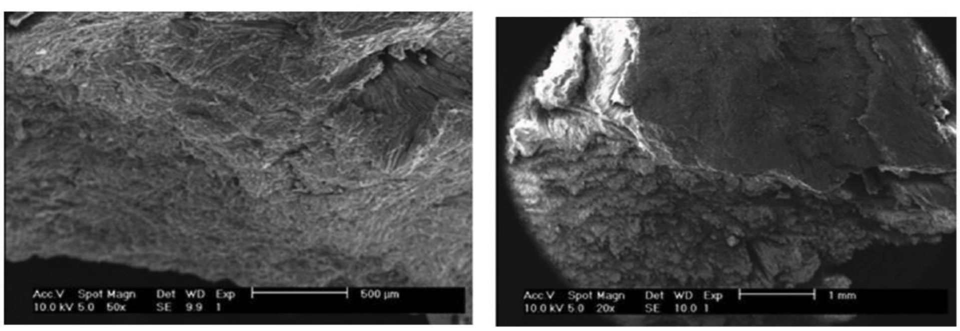

Figure 10. Microscopic images of the surface of coconut shell grain (Shafigh et al., 2014)

WASTE MATERIALS AS CEMENT REPLACEMENT

Silica Fume

Silica fume is a product of electrostatic capturing and tranquilising of silica dust with gasses discharged from electric arcs or alloys in the production process of silicon metal, particularly ferrosilicon alloys. This material has more than 80% non-crystalline silica with a diameter between 0.01 and 0.3 microns, which is about 50 to 100 times smaller than cement particles (Tavakoli et al., 2012). It is a 'super pozzolan' that can improve portland cement production properties. It modifies the physical characteristics of early cement paste and the micro-structural characteristics of cement paste after hardening. Research on the effects of silica fume on concrete started in 1987. The researchers of this study examined the effects of silica fume on high-strength concrete. The highest compressive strength achieved was for a sample containing 15% cement replacement with silica fume due to the filler effect and pozzolanic reactions (Yogendran et al., 1987). Brooks et al. (1998) also examined the factors affecting the high-strength concrete shrinkage containing this material. Mechanical characteristics in the short and long term on the high strength of concrete has also shown that by replacing 10% and 15% silica fume with cement, its compressive strength did not increase after 90 days and enhancement of strength occurred at the early curing ages. In addition, initial and final creep decreased with increasing amounts of silica fume (Mazloom et al., 2004). Studies on high performance concrete have shown that increasing the superplasticiser from 5 to 20% and decreasing the water-cement ratio from 0.31 to 0.26 caused an increase in compressive strength from 86 to 97 MPa (Sobolev, 2004). Table 3 shows the compressive strength in this scheme. Ganjian and Pouya (2005) investigated the effects of silica fume on resistance to sulfate attack in sea waters subjected to tidal waves and simulated by dry-wet conditions. The results showed that silica fume had more harmful effects on the durability of concrete (Tanyildizi & Coskun, 2008) but if fly ash were added to silica in concrete, the resistance to sulfate attack would improve (Wang et al., 2017) and in the case of reinforcing concrete to steel fibre containing microsilica, tensile strength significantly increased (Köksal et al., 2008). The simultaneous effects of silica fume and nano silica in concrete were investigated. The results showed that using both of these materials in concrete could increase the compressive strength of the concrete. This was because of the filler ability of the nanoparticles and a decrease in porosity (Heidari & Tavakoli, 2013).

Table 3
Details of HPC mixtures (Heidari & Tavakoli, 2013)

Proportions (kg/m^3)	SF (5%)	SF (10%)	SF (15%)	SF (20%)
Cement	426	449	468	478
Silica fume	22	50	83	120
Age	Compressive Strength (MPa)			
1 day	16.8	24.1	34.4	45.1
3 days	28.6	42.2	63	84.9
7 days	50.1	67.2	84.8	102.5
28 days	60	80	100	120

As the results showed, although silica fume could improve some of the mechanical features of concrete, it could reduce some durability characteristics. So it is recommended to use other admixtures beside silica fume in concrete to mitigate some of its negative features such as low durability.

Agricultural Waste

From agricultural waste, rice husk ash is the most applicable. The heating value of 1 ton of rice husk is equal to the thermal value of 0.48 tons of coal or 0.36 tons of fuel oil. If rice husk is used for fuel, it burns uncontrolled and many particles change to crystalline, which dramatically reduces pozzolanic activity. Therefore, if rice husk is going to be used in concrete, it must be burnt under controlled conditions and milled in the long run so that its pozzolanic properties increase. In a study, by calcining rice husk in 500 and using microsilica in high-performance concrete, the researchers obtained porosity decreased by development of the hydration of cement. Using these two materials improve the compressive strength and water absorption of concrete (Huang et al., 2017) and it was proved that rice husk ash has high pozzolanic potential (Mehta, 1992). It can also improve resistance to chloride attack, compressive strength and other mechanical properties (Antiohos et al., 2014). Adding a superplasticiser can also increase slump and decrease viscosity. Using rice husk ash can reduce the filling ability of concrete; however, paste viscosity and segregation rose sharply. By combining rice husk ash and fly ash the self-compacting and compressive strength properties of concrete improved (Le & Ludwig, 2016). Finally, studies have showed that in countries with limited production, rice husk ash can be a valuable additive in concrete products such as high-strength concrete and reconstructive mortars. Corncob has also been used in some studies. Corncob ash consists of more than 65% silicon dioxide and more than 70% combination of aluminium oxide and silicon dioxide. This reflects that the material is cemented and may have a viscous role in concrete (Adesanya, 1996; Adesanya & Raheem, 2009, 2010). Therefore, the use of these materials in the construction of concrete is practical, but they should be used more carefully in order to preserve their pozzolanic property and to strengthen the microstructure of the concrete.

Fly Ash

In power plants that are fuelled by coal, there are spherical particles in the gas that come from burning coal with a diameter of 0.1 to 0.15 mm; the particles are made up of about 85% of silicon, aluminium, iron, magnesium and calcium. Investigating the effects of fly ash started in 1999, and it was observed that the creep and shrinkage level of fly ash samples can be less than those of materials that do not use fly ash (Day, 1990). Also, if the curing temperature increases, the fly ash reaction will increase in the cement paste (Hanehara et al., 2001). This is not limited to only the amount of cement hydration but has effects on the type, characteristics, stability and the production process of hydration (Rojas & Cabrera, 2002; Ma, 2013).

According to ASTM C618, fly ash has two classes, Class F and Class C. The main difference between the two is on the levels of calcium, aluminium, silicon and iron content in the ash. Haque et al. (1984) pioneered the investigation of high-volume fly ash concrete. In 1987 and 1989, studies explored the incorporation of large quantities of fly ash in concrete. The method was about aerated and non-aerated concrete with 55% weight of fly ash substituted for cement in three strength levels of 21, 28 and 35 MPa. The results showed that the initial and final setting were not significantly influenced by replacing fly ash with cement by up to 55%. In addition, concrete containing 40 to 60% of fly ash showed lower compressive strength at an early curing age. However, it showed higher compressive strength compared to similar concrete without fly ash in 28 days (Naik & Ramme, 1987, 1989). Generally, Class F fly ash with good pozzolanic activities cause good mechanical properties, durability and low chloride permeability (Malhotra, 1990). By using a superplasticiser, poor abrasion resistance was generated compared to concrete without fly ash (Bilodeau & Malhotra, 1992). By using

50% fly ash in Class F, an appropriate concrete was obtained for the construction of reinforced concrete structures (Siddique, 2004). Chung-Ho et al. (2013) showed that in fly ash concrete, setting time and air percentage increased with enhancement of fly ash dose. Due to the fact that a high amount of fly ash and good pozzolanic activity reacts with CH of cement, the porosity of concrete decreases. Moreover, compressive and flexural strength of concrete shows an ongoing trend in 91 days and 365 days. Concrete mixtures containing fly ash with low loss of ignition had higher mechanical properties compared to concrete mixtures containing fly ash with high loss of ignition; in addition, increasing fly ash in concrete caused higher shrinkage due to drying at different ages (Chung-Ho et al., 2013). Figure 11 shows the development of shrinkage at different curing ages.

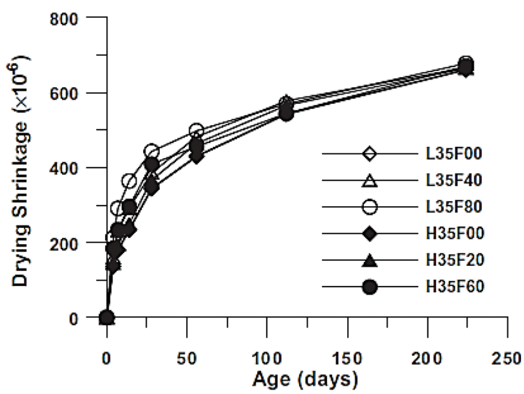

Figure 11. Development of shrinkage (Chung-Ho et al., 2013)

Investigations have also shown that fly ash can increase the compressive strength of concrete on long curing days and improve concrete durability by reducing permeability and increasing density. This type of material, in contrast to concrete waste and brick, is suitable for use in reinforced concrete.

Glass

Researchers have shown that glass particle size has an obvious effect on concrete performance .Smaller particles increase activity with lime, improve compressive strength and reduce shrinkage. The other results showed that the size of the glass does not lead to alkali-silica reaction but the high potential of high alkali glass powder particles leads to destructive expansion (Schwarz & Neithalath, 2007; Shao et al., 1999; Shayan & Xu, 2006; Shi et al., 2005). The experimental tests showed that the compressive strength of concrete samples with 10% glass powder was higher than the samples using fly ash. However, with 90 days' curing, the compressive strength and water absorption of fly ash concrete was higher than that of the glass powder samples. Also, increasing the curing time and adding fly ash to glass powder decreased the chloride diffusion and expansion of the alkali-silica reaction (Schwarz, 2007;

Schwarz et al., 2008; Schwarz & Neithalath, 2008). In high-performance concrete, if glass powder is shattered in micro scale, it will establish useful reactions with cement over time. The formation of calcium silicate hydrate (C-S-H) is very useful for the structure and characteristics of high-performance concrete (Vaitkevičius et al., 2014). Particle distribution and glass size curves can be seen in Figure 12.

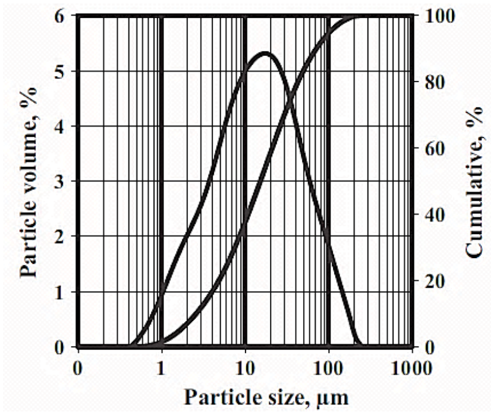

Figure 12. Particle distribution (Vaitkevičius et al., 2014)

In order to reduce ASR reaction, adding fly ash to the mixture of concrete and glass powder is recommended.

Ceramic Tile, Sanitary Ceramic and Clay Brick

The first studies on chemical properties of waste ceramic tiles were done in 2000. The results showed that waste tile has pozzolanic properties and the ability to be used in concrete construction (Shang, 2000; Toledo et al., 2007). Some studies investigated the use of clay brick waste from demolished buildings as a pozzolanic material. The results showed that this material could be replaced in cement (Lin et al., 2010). Tourgal and Jalali (2010) replaced 20% of the samples of ceramic waste as a pozzolan. The experimental results showed that a strength equal to 91% of the control sample can be reached by using these materials. It also reduced the permeability of concrete and increased its efficiency. Heidari and Tavakoli (2014) investigated waste ceramic tile concrete with silica fume to determine the effects of pozzolanic tile waste and confirmed pozzolan activity. Tile powder was used in different amounts in the concrete and its properties were measured. The results showed that increasing ceramic tile reduces compressive strength (Figure 13). However, if silica fume is added, the good effects will be doubled and the concrete defects will be covered. In these experiments the highest compressive strength was observed in the for 20% ceramic tile and 15% silica fume, while the lowest compressive strength was related to the 25% ceramic tile and 5% silica fume (Heidari & Tavakoli, 2010).

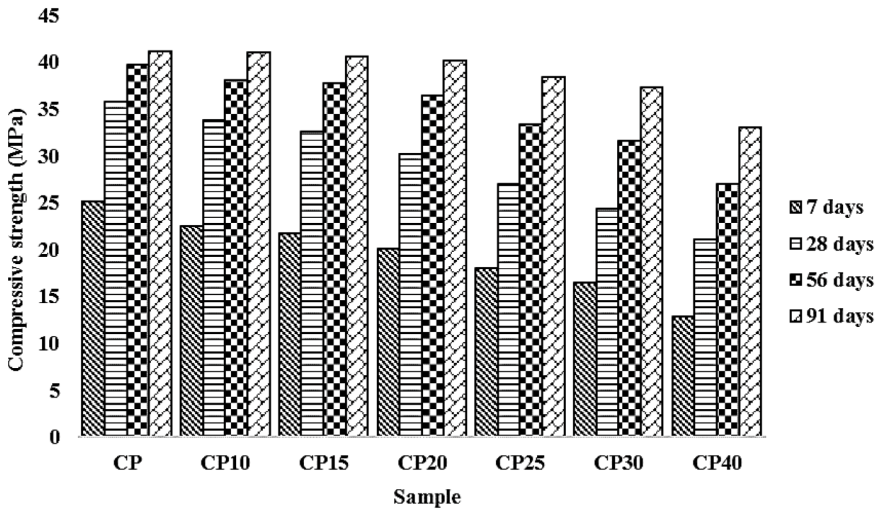

Figure 13. Compressive strength of samples (Phase A) (Heidari & Tavakoli, 2010)

CONCLUSION AND FUTURE WORKS

In the present study, the use of waste materials in concrete was reviewed. The intention of this study was to express the advantages and disadvantages of using waste in concrete, the effect of doing this and introducing materials that can be used in concrete. In order to clarify the details, the reviews were conducted in two parts, considering substitutes as aggregates and substitutes as part of cement. The most important studies in this field were reviewed and the properties of concrete that used waste were investigated. The results showed that waste material can be used in concrete. If waste is used as aggregates in concrete, it can lead to disposal of a large amount of waste. On the one hand, when a material is used as a substitution for cement in concrete, it has two advantages: less use of cement, an element that is very destructive upon the environment and the recycling of waste. It should be noted that further research is necessary to consider different conditions. It is not possible to make use of every kind of waste on every type of concrete as this may endanger the quality of the concrete, and in turn, is especially harmful to the environment. For functions such as filler, binder and separator, a portion of concrete can be replaced with waste as this causes little damage to the final mixture. On the other hand, usually in the process of production and transportation of waste material, harmful additives are added to the waste that can also be harmful to concrete. So further research into using modern equipment to recycle waste and the use of waste material in large projects in a way that causes no damage to concrete, leading to low environmental cleanup, which can be an action towards sustainable development, is needed. Finally, based on other research, the author's experience, lower negative effects and better performance, some types of waste were proposed for the production of concrete. These suggestions are shown in Figure 14 and Figure 15.

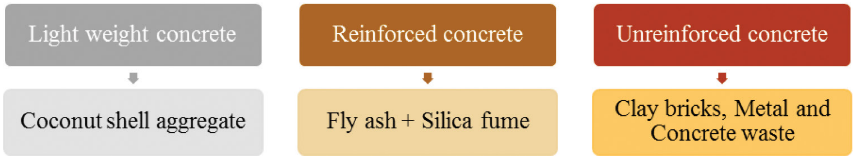

Figure 14. Suggestion of waste for special concrete production

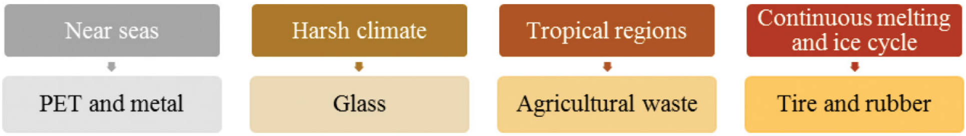

Figure 15. Suggestion of waste based on environmental conditions

However, it should be noted that regional and climatic conditions, as well as access to waste materials, are also effective in this selection. For future study, the authors suggest that researchers could do the following:

- Investigate using waste material and the feasibility of using sand or aggregates to create concrete for the construction of dams, tunnels, roads etc.
- Make sure of the durability and health, through long-term tests, of the concrete that uses waste
- Use neural networks or fuzzy systems for the prediction of parameters of other samples and for developing the results
- Evaluate the properties of other waste and new types of waste such as LCD waste etc.
- Investigate the usage of waste in concrete for improving the environment
- Investigate the use of waste in improving the durability of concrete sewerage pipes
- Improve concrete containing waste by finding its weaknesses and improving its characteristics by using combinations

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