Concrete Compressive Strength Development when Polyethylene Terephthalate Partially Replaces Sand

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Abstract

The diminution of sand and waste build-ups are two problems often faced today. This research was initialised to investigate the suitability of sand replacement with poly ethylene terephthalate (P.E.T) and also to evaluate the strength development of concrete where sand is replaced with P.E.T.In this research, a total of 40 numbers of 100mm x100mm x 100mm concrete cubes were made for the control specimen, 10%, 20%, 30% and 50% P.E.T replacement, half of which were for the 0.52 water/cement (w/c) ratio and the other half for 0.64w/c ratio. Two cubes of each replacement percentages were cured at three days and the other two at 28 days. The strength imposed at the point of failure marks their individual maximum strength, where they were recorded and analysed.

Keywords: concrete; PET; recycle; compressive strength

1.0 Introduction

Concrete, being one of the most important construction materials is widely used in the industry. Its use has sped up construction period and thus saves construction cost while maximizing a building's useful life. More research is being done to improve the concrete properties. On the other hand, not much is being looked into on how to maximise its usage, or the usage of the materials which constitute it. One of the materials in question is sand. Although there are countless amount of sand in this world, sooner or later it can run out in number, and diminish in existence. Therefore, there must be a solution to this problem. One of the potential materials for use is the polyethylene terephthalate or P.E.T in short. This is the subject to be tested in this research. It is a kind of polyester material for fibre, injection moulded parts, as well as blow-moulded bottles and jars (Kenplas Industry Limited, 2009).This material is often found to be made into mineral water bottles. For this research, waste bottles will be used as this type of material contributes the most to the wastes of plastics.There have been many reports that litter is mainly comprised of food packaging that has been disposed-off irresponsibly.

An overwhelming use of sand in the construction industry will lead to exhaustion of this material and could bring severe impact to the environment.Build-up of plastic wastes leads to an environmental problem. Wastes build up not only clutters space but also is an eye-sore, which can be hazardous in terms of toxic release when disposed incorrectly.The decreasing land area for disposal of wastes is also another problem faced. There has been reports on the issues of shortage of land, especially with the increase of the world population from day to day, which not only require residential places for living in, but also amenities like schools, hospitals, shopping malls, and other basic, not including the entertainment based buildings and facilities, which all require space.

This research aims to come out with an alternative resource to the natural sand that are used as fine aggregate in concrete production in order to minimise the rate of which sand is decreasing in quantity. The objectives of this research are to evaluate the strength development of concrete where sand is replaced with P.E.T and also to investigate the suitability of sand replacement with P.E.T. This research in only limited to the fine aggregates of concrete and the study on its strength development when it is partially replaced with P.E.T.Another limitation to this research is that it only studies the strength development for concrete of two water/cement (w/c) ratios. One of them is from the low w/c ratio (0.52) and another is of the higher w/c ratio (0.64).The strength of the concrete that will be measured are their initial compressive strength that is the strength at three days of curing and also its ultimate strength, that is its strength after 28 days of curing.

2.0 Literature Review

Concrete is a combination of hydrated Portland cement and aggregate. Common aggregates are sand and gravel (Klenck, 2000). The properties of the concrete depends upon the properties of its constituent materials, proportion of the mix, method of compaction and other controls during placing, compaction and curing (Gambhir, 1986). Therefore, the concrete's constituent materials play important role in ensuring that the concrete produced is of an acceptable standard and quality.

2.1 Sand

Sand grains are small particles, being the fine aggregate and have the purpose of filling the voids which exists between the larger particles of the coarse aggregates (Gambhir, 1986). Sand is of silica material in granular form,used to prevent shrinkage, crack, and also to improve the strength against crushing (Duggal, 1998).Among other natural material, sand was the best choice as it has the right characteristic to be used in conjunction with the other concrete constituent material. The sand particles are grains that are of 2mm and 0.05mm in diameters (Lagendijk, 2001). Standard sand should be of quartz, light grey or whitish colour, free from silt and organic impurities and should pass through the 850 µm with not more than 10 per cent passing through the 600 µm sieve(Duggal, 1998).

Sand cannot be planted, or regenerated as easily as trees. As such, the use of sand has to be monitored and planned, so that the availability of it remains. In the last 15 years, it has become clear that the availability of good quality natural sand is decreasing (Norman, 2008).In recent years, sources that are renewable and non-renewable are often being discussed. In the construction industry, the materials are also of these two sources.

Friendly utilisation of the natural resources of the rivers (State Environmental Conservation Department (ECD), Sabah, Malaysia, 2001) has been exercised. Another effort to reduce the rate of diminution of sand is to use alternative materials to imitate the properties of it. The Government has drawn attention towards utilising sea sand in place of river sand for the construction industry as a shortage prevails for river sand(Down to Earth, 2008).Crushed stone also continuously replace the natural sand and gravel for use in concrete production, particularly where construction rate is high, for example in densely populated areas like the United States (U.S. Geological Survey, 2010).Rock has been tested and made use to replicate sand. Recent surveys show that crushed rock sand, in the form of granite dust, is often used as fine aggregate to replace natural sand in various proportions (Building and Construction Authority Singapore, 2007).The use of crushed rock sand as replacement of natural sand since this is a viable alternative to natural sand and will help ease our reliance on natural sand for concrete is encouraged (Building and Construction Authority Singapore, 2007).More recent researches are done towards more common material that has less connection with concrete constituent materials, which contribute significantly to the environmental pollution. One of them is the use of plastics in concrete.

2.2 PolyethyleneTerephthalate (P.E.T)

Plastic are synthetic materials and are replaceable. Therefore, they do not face the problem of diminution. Apart from that, using plastic in concrete will help reduce the problem of plastic waste build-ups which consumes valuable space for disposal and also cost to properly manage the elimination of it. This chapter will focus on studying the possibility of using plastic as part of the concrete constituent materials with regards to its suitability.

The amounts of P.E.T bottles waste are steadily increasing globally (Ahmed & Mohammed, 2006). The majority of plastic bottles are not being recycled and are very quickly piling up and filling landfills around the world. Since plastic breaks down at a very slow rate, these will remain in our landfills for hundreds of years to come (UNESCO, 2003).The disposal of non-biodegradable wastes, including containers, bottles and cans made of plastic, used cars and electronic goods, leads to the pollution of land(iLoveIndia, 2015).

Polyethylene terephthalate (P.E.T) is one of the most valuable versatile engineering plastic which is used especially in the manufacturing of soft drink bottles (Abu Bakar*et al*, 2006).P.E.T is commonly used to package soft drinks, water, juice, peanut butter, salad dressings and oil, cosmetics, and household cleaners(Shyam Plastic Machinery, 2015).Plastic bottles shredded into small P.E.T particles of a maximum of 10mm in length and 5mm in width may be used successfully as sand-substitution aggregates incementitious concrete composites (Marzouk*et al*, 2006).P.E.T was also used as concrete-reinforcing P.E.Tfibre made out of the used P.E.T bottles. The researchers (Ochi *et al*, 2007) used a mixture containing fibrecontent at 3%. It was reported that the P.E.Tfibrewaseasy to handle. A positive effect where resins based on recycled P.E.T produce good quality precast concrete for precast concrete products for example building components for the construction industry among others(Rebeiz, 1996).Granulated waste materials such as plastics, glass, and fibreglass can be used in cementitious concrete composites without seriously hindering its mechanical properties (Shehata*et al*, 1996).The aggregate replacement of 20% by volume with P.E.T granules would result in a reduction of 2.8% in bulk-compacted mix density(Hassani*et al*, 2005). The value of flow in the plastiphalt mix was lower than that of the control samples.Apart from P.E.T, Fibre Reinforced Polymers (FRP) has also been used as reinforcement in concrete structures. This is made possible due to their mechanical and physical characteristics that are having high strength and light weight. These are advantages to have and will prove to be very much useful not only as concrete reinforcement in new constructions, but also in rehabilitation and pre-stressed concrete applications (Guadagnini*et al*, 2003).

3.0 Experimental and Computational Details

The mass of each of the concrete constituent materials has to be calculated based on the w/c ratio that has been pre-determined, that are 0.52 for the low w/c ratio and 0.64 for the high w/c ratio.

3.1 Weighing of Materials

The materials are then weighed according to the exact masses as calculated. It is important that the materials are obtained from the same batchto ensure that they have the same quality. Using the material obtained from the same batch will help minimize this risk, making the data obtained more reliable. The mix calculation was done with a number of five cubes, which allows some amount for wastage and also for shrinkage purposes. Another purpose for this is to have sufficient amount of concrete mix for the slump test, whereby the total volume of the cone does exceed that of four concrete moulds'. The required amount of P.E.T. is then acquired from Yonsin Plastic Industries located in the district of Klang, Selangor, in Malaysia.

3.2 Obtaining P.E.T

Before carrying out the research, the P.E.T has to be obtained. They then undergo a chain of processes turning it from raw water bottle shape to flakes, as can be seen inFigure 1.

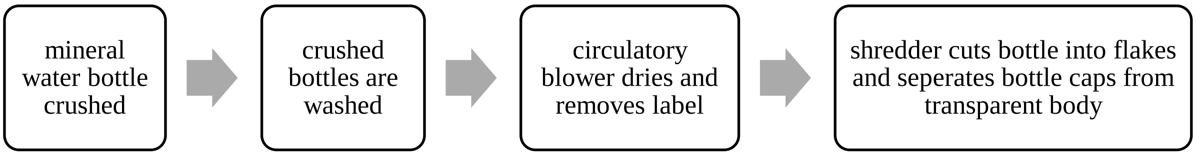

Figure 1 Flowchart of P.E.T shredding process. Source: (Vinesh, 2009)

However, the P.E.T material has to be fused with sand (Choi *et al*, 2009). Proper handling of wastes, sand and its fusion, heating and cooling will have an effect on the performance of P.E.T waste as sand replacement.Heat was applied to the P.E.T shreds and sand was poured over them.

3.3 P.E.T Properties

The P.E.T shreds were shredded in bulks. As they were to be recycled for manufacturing into other materials, the uniformity of the sized of the shreds were not too stringent, so long as they fall under the 10mm of length and 5mm in width. This was acceptable as the shred will be melted and fused with sand anyway, therefore the specifications of the shreds provided was fairly acceptable.The shredded P.E.T are flaky as can be seen inPhoto 1. This is good enough as the uniformity of the shape of the P.E.T shreds will enable it to be melted easily enough for fusion with sand.

Photo 1 Shredded P.E.T flakes. (Source: Barclay, 2008)

3.4 Fusion of Sand and P.E.T

As mentioned before, the investigation will make use of P.E.T shreds that have been melted and fused together with sand to reduce the usage of natural sand. To do so, the equipment needed is the gas torch or replaceable butane gas, obtained from the hardware store. The method of melting is a layer of P.E.T shreds are spread over the base of a metal tray as can be seen in Photo 2and the torch is run across it constantly until the P.E.T melts. Sand is then poured over this melted plastic so much so that covers completely the P.E.T layer, which then absorbs the sand.

Once the plastic turns solid, another layer of P.E.T is spread on top of the first, and the steps of burning the plastic and pouring sand over it is repeated two to three more times. The tray is quenched in water to let it cool before scraping the fused material out from the container. By this time, there will be huge chunks of fused material. It is necessary to change its shape and size to that of sand's. Therefore, the chunk is smashed and crushed using a hammer and then made finer by grinding in a food blender, which turns it into flakes again, but this time with the sand in it. The now granular material is sieved so that the correct size i.e. the size of sand which is the ones passing through the 600µm B.S sieve is used as the P.E.T and sand for that particular concrete mix. This step is repeated for the other percentages and w/c ratio. The process of concrete mixing was done as uniformly as possible to avoid the irregularity of texture and inconsistency of concrete-constituent materials in the mixture which affects the strength of the concrete at the later stage.

Photo 2 Fused sand and P.E.T

3.5 Compressive Strength Test

The concrete underwent compressive strength test, which is described in BS EN 12390-3 as the correct way of carrying out the compressive strength of test specimens of hardened concrete. In this research, a0.001m3 cube of concrete is cast, cured for the appropriate time, and is then compressed between two parallel faces as described in BS EN 12390-3. The condition of the concrete cube having undergone the compressive strength test can be seen in Photo 3. The stress at failure is taken to be the compressive strength of the concrete and can be read from the reading on the test machine display as in Photo 4 (LogicSphere, 2009).

Photo 3 Concrete cube condition after compressive strength test

Photo 4 Strength reading from compressive strength test machine

4.0 Results and Discussion

4.1 Comparison of 10% Replacement and Control Specimen

Table 1 Strength for 10% replacement and control specimen's

	3 days (0.52 w/c)	28 days (0.52 w/c)	3 days (0.64 w/c)	28 days (0.64 w/c)
control	14.38	35.95	11.91	29.77

10%	10.48	14.23	8.62	12.38

As can be seen in Table 1, there is a difference between 3-4kN/m^2 of compressive strength between the cubes of 10% replacement and the control cubes. The first reason is that the P.E.T does not perform as well as sand for the task of filling the inter-particle gaps. Therefore, there exists air voids in the concrete mixture and in the end, in the hardened concrete cubes which adversely affects the performance in terms of compressive strength. The second reason could be due to the flaky shape of the P.E.T which does not imitate that of sand's, which again reduces its suitability to act as sand replacement. The fact that the P.E.T was fused with the sand to increase its similarities of properties did not do enough to accommodate the compressive strength ability.

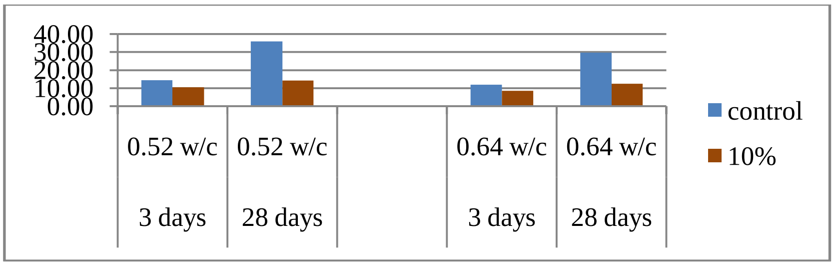

Figure 2 Graph for 10% replacement and control cubes' strength

From Figure 2, the compressive strength for concrete cubes of 0.64 w/c ratio are higher than those of 0.52 w/c ratio for both three days and 28 days. Higher w/c ratio means that there is a larger amount of water in the concrete mix, resulting with higher workability. However, the strength is lower as the concrete mix can be said to be more diluted with the existence of more water as compared to the amount of cement in the mixture. Water associates with the workability, while cement act as the bonding agent between the particles, which in the end, contributes to the strength of the concrete.

4.2 Comparison of 20% Replacement and Control Specimen

Table 2 Strength for 20% replacement and control specimen's

	3 days (0.52 w/c)	28 days (0.52 w/c)	3 days (0.64 w/c)	28 days (0.64 w/c)
control	14.38	35.95	11.91	29.77
20%	4.03	6.42	3.00	3.97

From Table 2, it can be seen that there is a difference of 8-10kN/m^2 of compressive strength for the three days test and a difference of 26-29kN/m^2 for the 28 days test for both 0.52 and 0.64 w/c ratio. Compared to the recorded strength when only 10% was replaced, the strength was lower. This shows that the higher the replacement, the lower the compressive strength of the concrete is. Similar to when comparing 10% replacement and the control cubes, the reasons for this difference of compressive strength is due to the dissimilar physical properties of P.E.T as to sand to act as the filler.

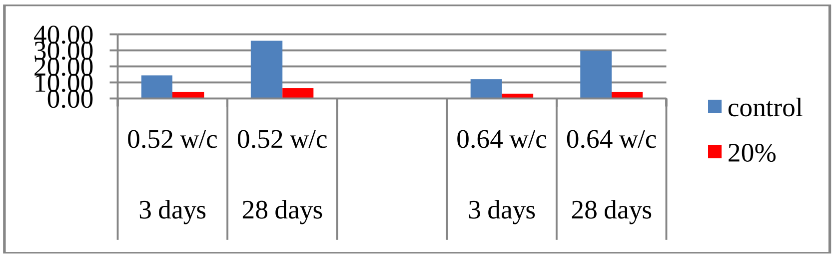

Figure 3 Graph for 20% replacement and control cubes' strength

FromFigure 3, there is a larger difference between the strength of the concrete cubes with 20% replacement and the control cubes. There is a lower compressive strength with a higher replacement percentage of P.E.T with sand for the concrete mix.

4.3 Comparison of 30% Replacement and Control Specimen

Table 3 Strength for 30% replacement and control specimen's

	3 days (0.52 w/c)	28 days (0.52 w/c)	3 days (0.64 w/c)	28 days (0.64 w/c)
control	14.38	35.95	11.91	29.77
30%	1.89	3.38	1.02	1.96

As can be seen in Table 3, there is a difference of 11-12kN/m^2 of compressive strength recorded for the cubes tested for the three days test and a difference of 28-32kn/m^2 for the 28 days tests. When taking into account the 3 replacements that are 10, 20 and 30%, the compressive strength gets even lower as the replacement is higher.

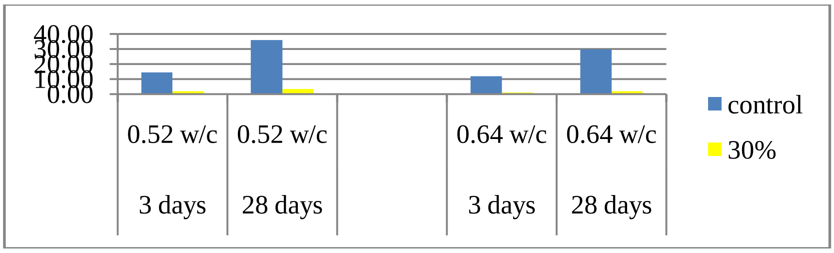

Figure 4 Graph for 30% replacement and control cubes' strength

Figure 4shows that the difference between the concrete with replacement of 30% gives an even higher difference of compressive strength after being tested in the laboratory when compared with the replacement percentages of 10 and 20%. The reason would be the samethat is the P.E.T fails to imitate, as a whole, the properties of sand, being filler for the gaps between the particles of concrete constituent materials that are the aggregates.

4.4 Comparison of 50% Replacement and Control Specimen

Table 4 Strength for 50% replacement and control specimen's

	3 days (0.52 w/c)	28 days (0.52 w/c)	3 days (0.64 w/c)	28 days (0.64 w/c)
control	14.38	35.95	11.91	29.77
50%	0.00	0.00	0.00	0.00

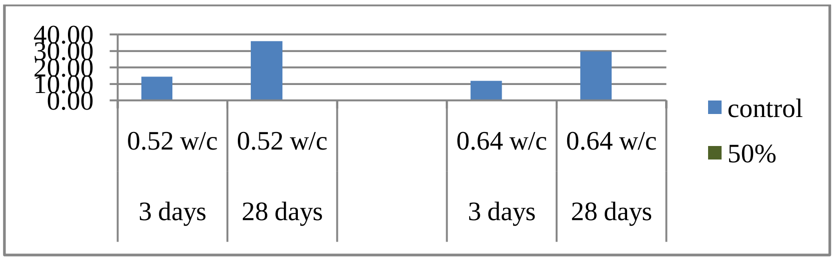

Figure 5 Graph for 50% replacement and control cubes' strength

Similar to the replacement percentages as the ones preceding it, the strength of the 50% replacement concrete cubes is comparatively the weakest recording 0.00kN/m^2 of compressive strength, as can be seen in Table 4 and Figure 5. The main reason for this can be seen during the slump test where the workability of the concrete mix was very high as there was a collapse of the mix slump. This is because the concrete mix is loose as there is less or no grip between the cement, sand and aggregates with the P.E.T.With this, there is a lower capability of load carrying by the hardened concrete of this mixture. Hence, the recorded strength during the compressive strength test was zero.

4.5 Factors for Decrease in Concrete Strength

Several factors for the strength decrease were identified. Firstly, the P.E.T pieces which were obtained from the factory were not cut in a uniform size. This does affect the quality of the mix as the strength of the concrete cubes is not distributed equally. This is because there are parts of the concrete cubes where there are more of the P.E.T material and at another part, there is less. Secondly, the amount of heat introduced to certain parts of the mix was not the same as to that of the other parts. This has an impact on the fusion of the P.E.T and sand,hence affecting the overall strength of the later hardened concrete.

5.0 Conclusion and Recommendation

There is the decrease in strength when the replacement percentageswereincreased for all four replacement percentages for both high and low w/c ratio. The strength of concrete cubes of the lower w.c. ratio (0.52) is comparatively higher than the cubes of the higher w.c. ratio (0.64).The results were conclusive enough to conclude that P.E.T is not such a suitable material for sand replacement in concrete production when fusing the P.E.T and sand in the particular method used in this research.Other methods of fusing sand with P.E.T, for example the use of furnace to evenly melt the plastic shreds instead of using butane torch, could be carried out in future researches.

6.0 References

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