Procedia
Environmental Science,
Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **6** (2019) (4) 565-574

Environmental Innovations: Advances in Engineering, Technology and Management,
EIAETM, 23rd-27th September, 2019

ENVIRO SAFE CONCRETE USING PLASTIC WASTE*

V Sai Neeraja, Ashutosh Sharma**

Lovely Professional University, School of Civil Engineering, Punjab, India

Abstract

On the planet after water the most widely used material was Concrete. About 4.5 percent of carbon dioxide was emitted because of manufacturing concrete. Concrete production contributes heavily to greenhouse gas emissions, thus a need exists for the development of durable and sustainable concrete with a lower carbon footprint. This can be achieved when cement is partially replaced with another material; such as fly ash/silica fume/copper slag. Environmental concerns arising from the over-dredging of sand have led direct economic impacts on concrete construction. A suitable environmentally friendly alternative to sand as plastic waste was found to match the huge demand from the concrete construction industry. This study is dealing with the behavior of self-compacting concrete (SCC) incorporated with different types of filler materials which replaces fine aggregate and cement partially in M40 mix. Plastic waste granules (PVC) for replacement of fine aggregate and fly ash is used as cement replacement.

Keywords: self-compacting concrete (SCC), fly ash, plastic granules (PVC)

1. Introduction

Utilization of industrial waste materials in concrete compensates the lack of natural resources, solving the disposal problem of waste and to find an alternative technique to safeguard nature. In the construction industry, the idea of sustainability encourages the use of waste products to replace raw materials, such as fine and coarse aggregates, cement and fibrous materials. This leads to sustainable, green and environmentally friendly construction by reducing the price of the components compared to disposing of the materials

Over the last decade, the concept and development model of Circular Economy has been gaining growing attention (Ghisellini et al., 2016). It aims to provide an alternative to

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*Selection and peer-review under responsibility of the ECOMONDO

** Corresponding author: e-mail: saineeraja6@gmail.com; ashutosh.21686@lpu.co.in

the traditional and dominant model (Ness, 2008) featured at consuming resources and then disposing it. Circular Economy emerges through three main actions, namely reduction, reuse, and recycle (Preston, 2012). According to Ghisellini et al., waste management, as a recovery of resources and environmental impact prevention, has become an important sub-sector of Circular Economy. On the other hand, limited natural resources, such as virgin aggregates, call for the utilization of recycled alternatives to meet the construction industry needs (Hana and Thakur, 2015). The increasing needs for sustainability in the construction industry and the movement of Circular Economy are driving the research of recycling and reusing waste streams, such as plastic waste obtained by recycling PET bottles/old PVC pipelines.

1.1. Self-Compacting Concrete:

A concrete mix can only be classified as Self-Compacting Concrete if it has the following mentioned characteristics. The main characteristics of Self Compacting Concrete are the properties in the Fresh state. The mixed design is focused on the ability to flow under its own weight without Vibration (FILLING ABILITY) and to retain homogeneity (PASSING ABILITY) without segregation (SEGREGATION RESISTANCE).

How does it work?

A self-consolidating must:

- You have the convenience that allows for self-improvement without external power.
- Store the same appearance during and after the process.
- It can easily be accessed by reinforcing.

Advantages:

- Improves Quality, durability, and reliability of concrete structure due to better compaction and homogeneity of the concrete.
- Ease of placement results in cost savings through reduced equipment and labor requirement. Less noise from vibrators and reduced danger from Hand Arm Vibration Syndrome.
- Improves working condition and productivity in the construction industry
- Faster construction
- Elimination of problems associated with vibration
- High segregation resistant

Research gap:

A study on investigating the effect of incorporating ultra-fine palm oil fuel ash (UPOFA) with a shredded recycled waste bottle in the form of Polyethylene Terephthalate (PET) on the engineering and transport properties of ultra-high-performance concrete. UPOFA was used as a partial replacement binder in varied proportions (20% and 40%) of the total cement binder, whereas shredded recycled PET bottles were added as reinforced fiber by 1% of the total mix volume. The greatest compressive strength was registered by a combination of 20% ultra-fine palm oil fuel ash and Polyethylene Terephthalate fibre in U20-UHPPGC (Alani et al., 2019). The combination of 40% ultra-fine palm oil fuel ash and PET fibers in U40-UHPPGC mix demonstrated a superior enhancement in terms of transport properties at the age of 28 days, such as porosity, initial surface absorption, gas permeability, water permeability and rapid chloride permeability. Thus, this research states pozzolanic UPOFA can improve the engineering and transport properties of ultra-high-strength concrete, but it lacks in knowing utilization of Flyash filler in self-compacting concrete.

A study on Effects of combined expansive agents and supplementary cementitious materials on the mechanical properties, shrinkage and chloride penetration of self-compacting concrete, the effects of incorporating expansive agent on the early-age mechanical properties, shrinkage characteristics and durability tests of self-compacting concrete (SCC) with different supplementary cementitious materials (SCMs) are investigated (Liu et al., 2019). Fly ash (FA), blast furnace slag (BFS) and Metakaolin (MK) are added as a partial replacement for cement respectively, while three different kinds of expansive agents are introduced in SCC at 15 wt%, 5 wt% and 1 wt% by cement weight. Results show that SCC presents a slightly lower compressive strength and modulus of elasticity compared to those of reference specimens at early ages, while the pozzolanic reactivity of SCMs leads to an increase the mechanical properties in the long-term strength development. The incorporation of combined magnesia expansive agent and liquid expansion agent indicates a significant reduction in the measurement of autogenous shrinkage and drying shrinkage. Additionally, the chloride ion penetration resistance of SCC is enhanced. Moreover, the combination of magnesia and liquid expansion agents refines pore structure and induces compensation for the auto-desiccation which results in high efficiency in the shrinkage reduction, but this research lacks in addition of PVC in combination of different filler material.

A study addresses the mechanical and fracture properties of self-compacting concretes (SCCs) containing plastic waste (PW) powder in varying amounts used as a cement replacement material. Partial amount of cement was replaced by PW powder at 5%, 10%, 15%, 20% and 25% by weight so as to design six SCC mixtures with a constant slump flow of 700 ± 30 mm, total binder content of 550 kg/m^3 and water-to-binder (w/b) ratio of 0.35 (Gesoglu et al., 2017). Mechanical characteristics of SCCs were tested for compressive and splitting tensile strengths, net flexural strength as well as modulus of elasticity on 28th day. Moreover, failure characteristics of the concrete were monitored via three-point bending test on the notched beams. The findings indicated that mechanical properties of PVC powder modified SCCs decreased while the concretes became less brittle, but it lacks in finding PVC granular utilization and caring the research.

An investigation was carried by four methodologies to design equivalent mortars. (Golaszewski et al., 2016) They are all based on the assumption that the fresh materials, mortar, and concrete can both be described as Bingham fluids. Thus, the measure of the rheological parameters of the mortars can be directly related to the equivalent parameters in concrete. Good models exhibit the same sensitivity as concrete to temperature, choice of superplasticizer and w/c changes as concrete. We propose two methods which conserve the w/c of concrete by calculating the appropriate paste-to-aggregate ratio. The results were validated experimentally for 3 temperatures, 2 superplasticizers, 2 cement types, and 2 w/c ratios, but it lacks in finding different strength parameters.

An attempt was carried out to develop some properties of self-compacted concrete (SCC) by adding waste plastic fibers (WPF) resulting from cutting beverage bottles. Many tests were conducted to investigate the effect of adding WPF on the fresh properties, whereas other tests were applied on that kind of concrete to study the effect of this type of waste on hardened properties. For this reason, different self-compacting concrete mixtures were designed at a constant water-to-binder ratio of 0.35 and 490 kg/m^3 of binder content. The class F fly ash was replaced with cement as 25% by weight. The eighth designated plastic fiber contents of 0, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75 and 2% by volume. The workability properties of self-compacting concrete mixtures were performed to slump flow diameter, T50 slump flow simultaneously, V funnel flow at the same time, and L-box height ratio (Al-Hadithi and Hilal, 2016). The 7, 14 and 28-day compressive strengths of self-compacting concrete were also measured. Moreover, the 7, 14 and 28-day flexural strengths of concretes were also measured. The test results showed that the plastic fibers have adverse effect on the fresh properties of self-compacting concrete and improvement by hardened properties, it lacks in dealing with industrial waste.

Experimental tests on concrete made of coarse aggregate or fine aggregate partially replaced with plastic waste derived from PVC waste sheets. The main goal behind this experiment is the inspection of important properties of concrete affected by the plastic waste addition, for the purpose of consuming the waste and production of an eco-friendly concrete. Results indicate that there is a chance to replace fine or coarse aggregate with PVC aggregate not more than 30% for the production of concrete with acceptable properties. At this plastic content, there is a margin loss of workability, absorption, and different strengths (Mohammed et al., 2019). Compressive and splitting tensile strengths loss was found not more than 8%. Elastic modulus of concrete is highly affected by the existence of PVC aggregate, especially when coarse aggregate is replaced. Abrasion resistance of concrete can be increased well as PVC aggregate is used instead of the natural one, especially coarse aggregate.

A study addresses the mechanical and fracture properties of self-compacting concretes (SCCs) containing plastic waste (PW) powder in varying amounts used as a cement replacement material. Partial amount of cement was replaced by PW powder at 5%, 10%, 15%, 20% and 25% by weight so as to design six SCC mixtures with a constant slump flow of 700 ± 30 mm, total binder content of 550 kg/m^3 and water-to-binder (w/b) ratio of 0.35 (Gesoglu et al., 2017). Mechanical characteristics of SCCs were tested for compressive and splitting tensile strengths, net flexural strength as well as modulus of elasticity on 28th day. Moreover, failure characteristics of the concrete were monitored via three-point bending test on the notched beams. The findings indicated that mechanical properties of PVC powder modified SCCs decreased while the concretes became less brittle, it lacks in dealing with industrial waste.

Environmental concerns arising from the over-dredging of sand have led to restrictions on its extraction across India, with direct economic impacts on concrete construction. A suitable environmentally friendly alternative to sand must be found to match the huge demand from the concrete construction industry. At the same time, waste plastic is rarely recycled in India, with as much as 40% left in a landfill. The dumping of such materials which degrade at extremely low rates meaning they persist in the environment is a long-term environmental concern. To tackle both issues, it is proposed to process waste plastic to create a partial replacement for fine sand in a novel mix for structural concrete, eleven new concrete mixes are evaluated to study five plastic material compositions, three groups of particle sizes, three different aspect ratios, and two chemical treatments and establish an appropriate choice of material to act as partial replacement for sand. The results show that replacing 10% sand by volume with recycled plastic is a viable proposition that has the potential to save 820 million tonnes of sand every year (Thorneycroft et al., 2018) Through suitable mix design the structural performance of concrete with plastic waste can be maintained, it does not deal with adoption of industrial waste in concrete mix& making it as a enviro safe concrete.

The main objective of this study is to:

- Obtain optimum mix
- Check the applicability of the use of fillers like fly ash and PVC for production of the concrete.
- To reach the aim the following tasks were defined and solved:
- Evaluating the fresh properties of concrete using industrial waste-Fly ash and PVC granules as replacements in cement and coarse aggregate and knowing its workability when used in self-compacting concrete
- Evaluating the hardened properties of concrete using industrial waste-Fly ash and PVC granules as replacements in cement and coarse aggregate and knowing its workability when used in self-compacting concrete
- Analysis of results, drawing a conclusion of optimum mix proportions that can be adopted when using latest IS 10262-2019 mix guidelines.

2. Materials and methods

2.1. Cement

Cement used in experimental work was Ordinary Portland Cement (OPC) of 53 grade from ULTRATECH brand.

2.2. Fly ash

Fly ash (or) ash as phosphorus is a waste of charcoal Collected by mechanical separators from the combustion gases of thermal power plants. Composition Differences in the type of fuel contained in lamps and smoke types. Fly Ash of spherical glass particles with diameters of 1 to 150 mm and also passes through a 45-inch microscope.

2.3. Plastic granules: (PVC)

PVC is the most widely used member of the vinyl family. It is most commonly used in pipe and fittings. PVC offers excellent corrosion and weather resistance. It has a high strength-to-weight ratio and is a good electrical and thermal insulator. PVC is also self-extinguishing per UL flammability tests. PVC may be used to temperatures of 140°F (60°C) and is readily available in sheets, rods, and tubing. PVC may be cemented, welded, machined, bent and shaped readily.

Table 1. Typical properties of PVC

SL.NO	*Properties*	*Test results*
1	Density (lb/in^3) (g/cm^3)	0.051- 1.41
2	Water absorption, 24 hrs (%)	0
3	Max operating temp (°F / °C)	140 / 60
4	Tensile strength (psi)	7,500
5	Flexural strength (psi)	12,800
6	Hardness	115 (Rockwell R)
7	Heat deflection temp (°F / °C) at 264 psi	176 / 80
8	Melting temp (°F / °C)	N A

Table 2. Mix proportions of SCC

Mix Designation	*Proportions of binding materials (cement : fine aggregate : coarse aggregate)*	*Fly ash %*	*PVC %*
MIX1	1:1.3:2.6	0	0
MIX2	1:2.12:1.56	10	3
MIX3	1:2.31:1.64	20	6
MIX4	1:2.56:1.73	30	9

Fine aggregates were replaced by plastic granules (PVC) from 0% to 9% of mix interval (3%, 6%, and 9%). Cement was replaced by industrial waste- fly ash from 0% to 30% of mix interval (10%, 20%, and 30%). The superplasticizers of 'Conplast SP430' dosage are added to the mix to get flowability. Totally the three different mix proportions of SCC were designed and tested, for further fresh properties will check using slump cone, U-box, V-funnel, and L box tests. For hardened properties such as compressive strength and split tensile strength are to be done to analyze strength parameters. All these tests are performed at the age of 7, 14 and 28 days and compared the results between the nominal mix concrete and self-compacting concrete properties.

3. Results and discussion

3.1. Study of fresh concrete

The experimental investigations made on the self-compact ability of concrete with fly ash as filler material can be characterized by the following properties: filling ability; passing ability; segregation resistance. A concrete mix can only be classified as self-compacting concrete if the requirements for all three characteristics are fulfilled.

3.2. Slump flow test

The slump flow is part of the SCC testing that is most commonly used for the moment. The slump value of about 650 mm to 800 mm is within the acceptable range. The higher the flow rate (SF), the greater it’s capacity to fill and must be at least 650 mm for SCC.

3.3. L-box test

The L-box value is the ratio of the concrete level at the end of the box after the test is completed at the end of the box after the completion of the test. L box containing chimney and "channel" section after completing the concrete level test in the chimney, it is recorded that H1 levels of concrete in the pane are recorded as H2. L-box value (called "L-box ratio" "Blocked value" or "Blocking factor") is just H2 / H1. The generally acceptable value for the L box values is between 0.8 and 1.0. If the concrete is fully aligned after the completion of the test, the value of the L box will be 1.0. Conversely, if the concrete is difficult to reach, the L-box value will be zero

3.4. U-box test

Concrete is placed on the left side of the box. An alternative version of the apparatus features a flat bottom instead of a curved bottom. Ideally, the box should be made of clear plastic to permit the observation of the concrete in the box. To start the test, the door dividing the two halves of the box is opened and concrete is allowed to flow from the left half of the box into the right half. Reinforcing bars are placed at the location of the door. Although the spacing of the bars is adjustable, the most common arrangement is 13 mm diameter bars with a clear spacing of 35 mm. The time from the opening of the door until the concrete ceases to flow is recorded. The height of the concrete on each side of the box is measured. A truly self-leveling fluid will rise to the same height on each side of the box. Concrete with good filling ability should reach a height of at least 30 cm on the right side of the box. In some versions of the test, a surcharge load is applied to the concrete on the left side of the box. This surcharge load is unnecessary for self-compacting concrete and is generally not used.

3.5. V-funnel test

It is used to determine the filling ability (flowability) of the concrete with a maximum aggregate size of 10mm. The funnel is filled with about 12 liters of concrete and the time taken for it to flow through the apparatus is measured. After this the funnel can be Refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly. The results of the study are presented in Tables 3, 4, and 5. The effect of fly ash and Plastic granules on compressive strength, Split tensile strength of concrete is studied in this investigation. Cubes and Cylinders prepared with different proportions have been cured for 7 days, 14 days, 28 days, and prior to testing. The average compressive strength of concrete of at least three cubes (150mm x 150mm x 150mm) is noted down. For the split tensile test of concrete the cylinders, prepared with different admixtures percentages have been cured for 28 days prior to testing.

Table 3. Properties of fresh concrete (SCC)

Concrete Mix	***Slump flow***		***V-funnel***	***L-box***
	MM	***T_{50}(sec)***	***T_{50}(sec)***	***H2/H1***
MIX 1	520	14	16	1.0
MIX 2	680	10	7	1.32
MIX 3	690	9	7	1.32
MIX 4	680	10	7	1.28

The above table represents the properties of fresh concrete, i.e., slump flow, V-funnel test, L-box test. Slump flow results are in acceptable range for SCC. The least T50 seconds was observed for mix3. All the SCC mixes show equal filling ability i.e. T50 value was observed as 7 seconds. The blocking factors were equal for mix2 and mix3, lesser for mix1.

3.6. Compressive strength of concrete

The compressive strength is defined as a charge that damages a standard sample (Ex 100 mm Cube, according to ISI), which is divided by a circular surface in high compression. The compression strength test should be done on a 150mm cube. Put the cube in the compression checker. A green button is pressed to start an electric motor. When the load is gradually applied, the piston is increased along with the bottom, and thus the load pattern must be 300 KN per minute and can be controlled by the speed control button. The last charge is recorded for each model. The valve was triggered and the valve was dropped. The values are recorded in the table and calculations are made.

Table 4. Compressive strength on SCC

Concrete Mix proportions	***Compressive strength N/mm^2***		
	7days	***14days***	***28days***
MIX 1	26	37	45
MIX 2	26	37.5	46
MIX 3	26.5	37.5	46.5
MIX 4	25	35	44

The maximum compressive strength was attained for 28 days in mix3. So it can be considered as optimum mix, so utilization of 20% fly ash and 6% PVC in SCC can be adopted to give high compressive strength.

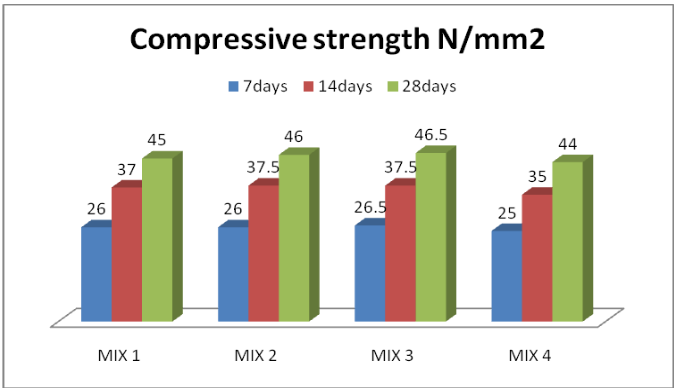

Fig. 1. Compressive strength of Mix 1,2,3&4 at 7,14 & 28 days.

Compressive strength = average load/ area of cross section

3.7. Split tensile strength

The split tensile strength tests of concrete can be broadly classified into direct and indirect methods. The first method suffers from a number of difficulties relating to placing or holding the specimen property in the testing machine without increasing the stress concentration and difficulties in applying axial load free of eccentricity on the specimen. Because of the difficulties involved in conducting the direct tension test, indirect test such as split tensile method has been used. The split tensile test was conducted for various cylindrical specimens (150mm x 300mm) at the age of 28 days in the compression testing machine of capacity 200 tons. Cylindrical splitting tension test is also sometimes referred as "Brazilian test ". This test was developed in Brazil in 1943.

$$\text{Split Tensile Strength} = \frac{LOAD}{AREA} = \frac{2P}{\pi LD}$$

Table 5. Split tensile strength on SCC

Concrete Mix proportions	*Split tensile strength N/mm²*		
	7days	*14days*	*28days*
MIX 1	3	3.2	3.6
MIX 2	3	3.6	4
MIX 3	3.2	3.6	3.8
MIX 4	2.8	3.2	3.6

The visual representation of the data from Table 5 is given in the Fig. 2. Form the Fig. 2 the maximum split tensile strength was attained for 28 days in mix2. So mix2 can be considered as optimum mix, so utilization of 10% fly ash and 3% PVC in SCC can be adopted to give high split tensile strength.

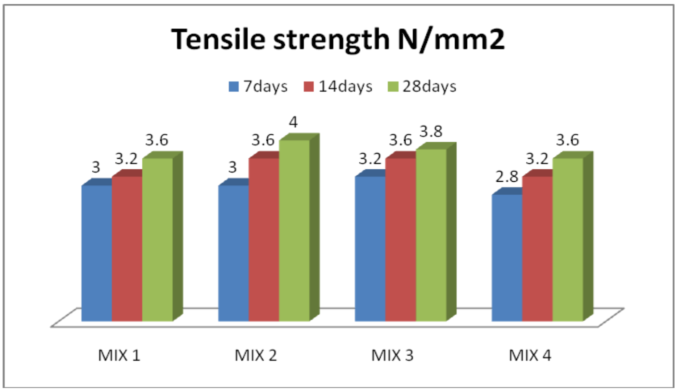

Fig. 2. Split tensile strength of Mix 1, 2, 3, and 4 at 7, 14, and 28 days.

4. Concluding remarks

Based on the investigation conducted for the study of the behavior of self-compacting concrete the following conclusions have arrived.

- Fly ash and PVC waste were used as fillers for the concrete production instead of cement and fine agglomerates respectively.
- Use of Fly ash as cement replacement increases consistency & a substantial improvement in the flow and strength properties of concrete was achieved.
- Different ratios of the filler were investigated and compared. The results show, that the fresh properties of concrete with 20% fly ash and 6% PVC (Mix 2) shows good results when compared to normal concrete from Table 3.
- The use of superplasticizer makes it possible to get a mix with low water to cement ratio to get the desired strength.
- The maximum compressive strength and tensile strength were attained at the age of 28 days for all the mixtures investigated. Nevertheless, the best result was obtained for mixture 2, which is better than even for the standard concrete.
- The compressive strength of normal concrete is almost equal to the strength of 10% fly ash & 3%PVC concrete (Mix 1) from Table 4.
- The compressive strength of normal concrete is more when compared with 20% fly ash & 6%PVC concrete (Mix 2) from Table 4.
- Tensile strength of the concrete also increases with increase in Fly ash content up to the 20% fly ash & 6%PVC concrete (Mix 2) from Table 5.
- The maximum compressive strength and tensile strength attained at the age of 28 days of curing were found to be 46.5 N/mm^2 and 4 N/mm^2 respectively, irrespective the replacement levels for the fly ash& PVC based SCC, which can be used as structural concrete.

Thus, the use of industrial wastes can make eco-friendly concrete and can be used for sustainable construction works.

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