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Mechanical Performance of Self Consolidating Concrete containing Plastic Waste Particles

[N.G. Ozerkan[1], D.D. Tokgoz[1], O.S. Kowita[1], S.J. Antony[2]]

1Center for Advanced Materials, Qatar University
2Institute of Particle Science and Engineering, School of Chemical and Process Engineering, University of Leeds

Abstract— **This work is aimed to evaluate the effect of recycled and virgin high density polyethylene (HDPE) and low density polyethylene (LDPE) waste granules on self-consolidating concrete mixture including Municipal Solid Waste Incineration (MSWI) fly ash. Within the scope of experimental, five SCC mixtures were designed. The effect of plastic particles as coarse aggregate substitution has been evaluated by the mechanical and physical tests on fresh and hardened concrete. At the end of the study, the drying shrinkage behavior and compressive strength of SCC mixtures were improved by the addition of plastic waste granules.**

Keywords— Plastic waste particles, durability, mechanical properties, self-consolidating concrete, municipal solid waste incineration fly ash

I. Introduction

Conventional plastic consumption has been dramatically increasing in human life with the development of countries and the society. Its low manufacturing cost, low density, strength, light weight, user-friendly designs, long life and excellent mechanical, thermal, chemical properties are the beneficial properties and factors behind such extraordinary growth. The widespread use of plastics include containers and packaging, automotive and industrial applications, medical devices and healthcare applications, and other uses. However, this great activity in the consumption of plastic contribute to large amount of plastic waste which is considered to be a big problem for the environment due to its very low biodegradability.

Assist. Prof. Nesibe Gozde Ozerkan
line 1 Center for Advanced Materials / Qatar University
line 2: Qatar

Dr. Deniz Tokgoz
line 1 Center for Advanced Materials/Qatar University
line 2: Qatar

Osama Kowita
line 1 Center for Advanced Materials/Qatar University
line 2: Qatar

Assoc.Prof. Simon Joseph Antony
line 1 2Institute of Particle Science and Engineering, School of Chemical and Process Engineering, University of Leeds
line 2: United Kingdom

One of the rational approaches for the disposal of this waste for the economical and environmental protection is the possible use of this waste in concrete and concrete applications. In recent time, significant research tends to study the possible use of these wastes in cementitious materials and concrete (Siddique 2008, Yang et al. 2015, Rai et al. 2012, Safi et al. 2013, Al-Manaseer and Dalal, 1997, Avila and Duarte, 2003, Batayneh et al. 2007, Rebeiz and Craft 1995, Rossignolo and Agnesini, 2004). Rebeiz (1995) investigated the effect of recycled polyethylene perephthalate (PET) on the time and temperature dependent properties of polymer concrete in order to evaluate the possible use of the material in precast applications, and the results showed that PET can achieve high early strength except at high temperatures. Naik et al. (Naik 1996) have shown, in their work that chemical treatment has a major effect on performance of the waste high density polyethylene (HDPE) filler in concrete, and increasing the amount of the plastic particles in concrete decreased the compressive strength. Choi et al. (Choi 2005) studied the possible use of PET bottles as lightweight aggregate in concrete and the study showed that the compressive strength and the density of concrete were reduced, while the workability was improved as the replacement ratio of plastic waste as a sand-substitution in concrete increased. The lower compressive strength and better or similar workability with the increase of the replacement ratio of plastic waste was also proved by other researchers (Batayneh et al. 2007, Ismail and Hashmi 2008, Panyakapo 2008, Remadnia et al. 2009, Frigione 2010, Saikia 2014). However, it was also proved that the addition of PET into aggressive environments exposed mortars showed better chemical attack resistance and better durability properties (Rebeiz 1995, Marzouk et al. 2007). On the other hand, the results obtained by Jo et al. (Jo et al. 2008) shows that the strength and elastic modulus of concrete made with a resin based on recycled PET increases with increasing resin content up to certain point. In another study, instead of PET particles, recycled plastic waste sourced from scraped PVC pipes and replaced with sand in concrete design (Kou et al. 2009). At the end of their study, they concluded that the strength and workability were reduced while ductility was improved with the increase of PVC granules replacement, but drying shrinkage and the chloride ion penetration were improved. The use of mineral admixture with PET waste aggregate was also evaluated in Akcaozoglu et al. study (2010), and the results proved that the use of plastic waste granules with granulated blast furnace slag (GBFS) in mortar is very helpful solution for environmental concern, and can improve the mechanical behavior of concrete. Gadea et al. (2010) used the rigid polyurethane foam wastes in lightweight mortar and evaluated the mechanical and permeability properties. The results showed that an increase in the amount of polyurethane waste adversely affected the mechanical properties and density of lightweight mortar while developing workability and permeability. The effect of curing conditions on the mechanical and durability properties of plastic waste included concrete mixtures has also been evaluated and concluded that the drier curing regimes resulted in less mechanical and durability problems (Ferreira et al. 2012, Silva et al. 2013).

However, it has observed that the most of the studies are aimed the effect of plastic waste as aggregate substitution on ordinary concrete or mortar mixtures, while there are limited studies on the usage of plastic waste in self-consolidating concrete. Safi et al. (2013) introduced the use of plastic waste as fine aggregate in the self-consolidating mortars. They concluded that the fluidity is substantially improved by incorporating the plastic waste particles into the concrete or mortar mixtures, and up to 50% replacement of waste particles with sand showed acceptable compressive strength for self-consolidating concrete. Yang et al. (2015) have also studied the properties of self-consolidating lightweight concrete including recycled plastic waste particles, and the results showed that the slump value is improved with plastic waste incorporation, and the mechanical properties can be improved with the plastic waste incorporation when it is used up to 15% replacement.

The presented study aims to evaluate the effect of recycled and virgin high density polyethylene (HDPE) and low density polyethylene (LDPE) waste granules on self-consolidating concrete mixture including Municipal Solid Waste Incineration (MSWI) fly ash. The effect of plastic particles as coarse aggregate substitution has been evaluated by the mechanical and physical tests on fresh and hardened concrete.

II. Materials and Methodology

A. Materials

The cementitious materials used in this work were an ordinary Portland cement (ASTM Type I), Municial Solid Waste Incineration (MSWI) fly ash, and silica fume since MSWI fly ash showed extremely low silica content as 1.89%. The chemical analysis and the physical properties of cementitious materials are presented in Table 1. Sand (or fine aggregate) having 2.73 specific gravity, unit weight of 1.45 kg/l and water absorption of 2.15%, and crushed limestone (or coarse aggregate) having 3.095 specific gravity, unit weight of 1.93 kg/l and water absorption of 0.62% were procured from the Qatar Sand Treatment Plant and used as the aggregate. The straight cylindrical micro steel fibers with a brass coating had 6 mm length and 0.16 mm diameter, and the aspect ratio (L/d) 40 was also used in all concrete mixtures. Recycled polyethylene granules were collected from one of the plastic recycling companies in Qatar, namely Doha Plastic Company. In this plant, firstly HDPE and LDPE plastic wastes were separated and then they were processed separately. Separated HDPE and LDPE wastes were washed and crushed into scraps. Prior to extrusion, these crushed scraps were dried and then fed into the extruder and extracted as plastic wires. Finally, these plastic wires were cut into cylindrical granules by cutter. The average diameter was 4.0 mm for r-HDPE and 3.0 mm for r-LDPE. The average length was 3.5 mm for r-HDPE and 3.0 mm for r-LDPE. A polycarboxylic-ether based type superplasticizer with a specific gravity of 1.11±0.03 was used in all concrete mixtures in order to obtain the desired flowability of SCC, and kept constant in all mixtures.

B. Mixture Proportions

The main objective of the presented paper is to study the effect of incorporating plastic particles on the workability and mechanical properties of micro-steel fiber reinforced SCC. Within the scope of experimental, five SCC mixtures were prepared and presented in Table 2. As seen from the table, the control mixture included only the Portland cement, MSWI fly ash, silica fume and micro-steel fiber. The virgin and recycled high density polyethylene and low density polyethylene particles were incorporated by replacing 10% of the coarse aggregate by weight, and named as V-HDPE, V-LDPE, R-HDPE and R-LDPE, respectively. Since the SCC characteristics such as slump flow diameter, V-funnel time were expected to be obtained, water was gradually added to the mixtures and therefore the water to binders ratio (w/b) was changed.

Table 1. Characteristics of Cementitious Materials

Chemical Composition	Portland Cement	Fly Ash	Silica Fume
CaO (%)	64.95	45.0	1.05
SiO_2 (%)	21.92	1.89	89.5
Al_2O_3 (%)	4.32	0.784	0.32
Fe_2O_3 (%)	3.78	0.601	0.38
MgO (%)	2.16	0.552	0.1
SO_3 (%)	2.08	8.67	0.1
Alkalies (Na_2O+ 0.658 K_2O) (%)	0.68	18.3	-
Loss on Ignition (%)	1.00	1.9	2.3
Insoluble Residue (%)	0.68	1.06	1.0
Physical Properties			
Specific Gravity	3.09	2.25	2.01
Blaine Fineness (cm^2/g)	3527	-	-
Mechanical Properties			
f_c', 2 days (kgf/cm^2)	218	-	-
f_c', 7 days (kgf/cm^2)	295	127	135
f_c', 28 days (kgf/cm^2)	410	186	-

Table 2. Micro-Steel Fiber Reinforced Self-Consolidating Concrete Mixture Proportions

Mix Design Label	w/cm	Cementitious Materials (kg/m³)			Water (kg/m³)	SP (kg/m³)	Aggregate (kg/m³)		Steel Fiber (kg/m³)	Plastic Granule (kg/m³)
		Portland Cement	Fly Ash	Silica Fume			Fine	Coarse		
Control	0.49	320	40	40	180	12	1012.2	831.2	16.6	0
V-HDPE	0.54	320	40	40	180	12	1012.2	831.2	14.4	4.97
V-LDPE	0.38	320	40	40	180	12	998.9	820.3	14.4	4.96
R-HDPE	0.52	320	40	40	180	12	874.8	718.4	14.4	4.96
R-LDPE	0.50	320	40	40	180	12	871.8	716	14.4	4.94

C. *Test Methods*

1) Preparations and Samples Casting

In order to conduct the experimental program, nine 100x200 mm cylinder specimens, six 40x40x160 mm prism specimens, and nine 25x25x280 mm specimens were manufactured for each mixture. After mixing procedure, fresh concrete tests were performed and specimens were casted. After 24 hours, the specimens were demolded and immersed in a water tank until the age of testing (7 days, 28 days and 90 days) for mechanical tests.

2) Physical Properties

The penetration resistance method was applied on fresh concrete in order to determine the setting time of fresh concrete. Based on the methods standardized by Specification and Guidelines for SCC prepared by EFNARC (2005), the flowability properties of SCC mixtures were evaluated by measuring the slump flow time (T_{50}) to reach a concrete 50 cm spread circle, V-funnel flow time and slump flow diameter. The physical properties of hardened concrete were evaluated by the drying shrinkage method by measuring the length change of the samples according to ASTM C 596 after demolding, and 4, 11, 18, and 25 days of curing by evaluating the average value of nine specimens from each mixture.

3) Mechanical Testing

Three point bending test and uniaxial compression were carried out at 7, 28 and 90 days of water curing. The compressive strength test was performed on nine cylinder specimens (100x200 mm) at 7, 28, and 90 days of curing by using three cylinders at each age according to the procedure defined in ASTM C 39. The flexural strength test was performed on six prism specimens (40x40x160 mm) at 7 and 28 days of curing by using three specimens at each age according to the procedure defined in ASTM C 293.

III. Results and Discussion

A. *Physical Properties*

In order to evaluate the physical properties of plastic waste incorporated fresh SCC mixtures, the flowability tests including slump flow diameter and time (T_{50}) and V-funnel time were determined, and the results are presented in Table 3 and Figure 1. As it is presented in the table and figure, the slump flow times were in the range of 2-3.14 s, the slump flow diameters of all mixtures were in the range of 59.5-67 cm, V-funnel time was less 7.11 s and more 5.47s, and the initial and final setting times of the mixtures ranged from 1:10 to 4:50 h:min, and from 2:40 to 6:30 h:min, respectively. According to EFNARC (2005), a slump flow times typically varies between 2 and 6 seconds, a slump flow diameter ranges from 65-80 cm, and V-funnel time ranges from6-12 s. Although the additions of plastic particles into the SCC mixtures decrease the flowability except flowing diameter, the values are in the accepted range established by EFNARC and ASTM standards. Furthermore, according to ASTM C 403, the initial and final setting time of conventional concrete is accepted as more than 30 min and less than 10 h, respectively. However, for SCC mixtures, because of high dosage of superplasticizer and low cement content, the setting time is 3-4 hours longer than conventional concrete. As it is seen from the figure and the table, it is also concluded that the addition of plastic granules to SCC mixtures, the hardening time is decreased around 25% for initial and final setting time.

Moreover, the physical properties of hardened SCC mixtures were evaluated by drying shrinkage test and the results are presented in Figure 2. It can be concluded from the graph that the drying shrinkage of SCC mixtures including recycled or virgin plastic waste granules decreases, which is almost 20% of control mixture. Therefore, it can be concluded that the plastic waste granules improve the drying shrinkage behavior of SCC mixtures which is in agreement with the finding of previous studies.

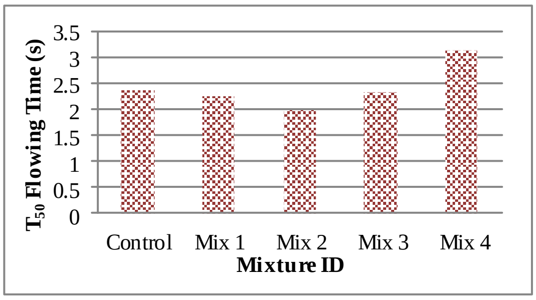
Table 3. Fresh Concrete Test Results of SCC Mixtures

	Slump flow		V-funnel time (s)	Setting Time	
	T50 Flowing time (s)	Flowing diameter (cm)		Initial (min)	Final (min)
Control	2.39	67	5.47	450	630
Mix 1	2.26	59.5	7.01	150	270
Mix 2	2	59.5	7	120	240
Mix 3	2.36	61.5	6	220	360
Mix 4	3.14	61.5	7.11	110	247

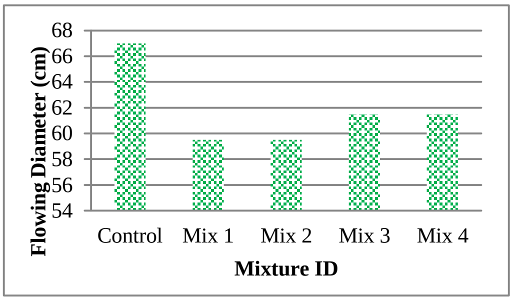
B. *Mechanical testing*

The mechanical properties of SCC mixtures including plastic particles were evaluated by compressive strength and flexural strength tests and the results are presented in Figure 3 and 4, respectively.

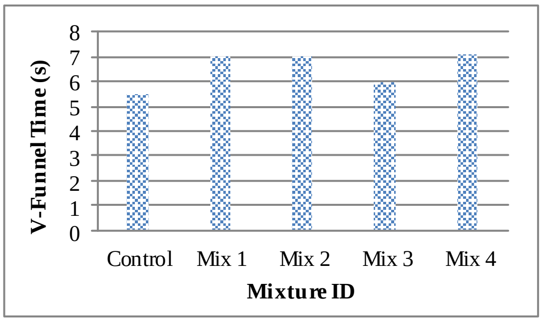
As seen from the compressive strength test results, the SCC mixtures including virgin high density polyethylene or recycled low density polyethylene waste particles have same compressive strength values with the control mixture which is differ from some published studies (Batayneh et al. 2007, ismail and Hashmi 2008, Panyakapo 2008, Remadnia et al. 2009, Frigione 2010, Saikia 2014); and consistent with other studies about using plastic particles with cementitious materials (Akcaozoglu et al. 2010). For the flexural strength test results, it can be concluded that up to 7 days of curing day, the control mixture has the highest flexural strength, however, at 28 days of curing day, recycled high density polyethylene waste particles incorporated mixes has the highest flexural strength value.



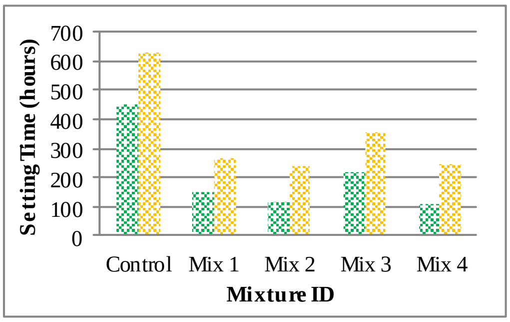
(a)



(b)



(c)



(d)

Figure 1. Fresh State Properties of SCC Mixtures; **(a)** T_{50} Flowing Time, **(b)** Flowing Diameter, **(c)** V-Funnel Time, **(d)** Setting Time

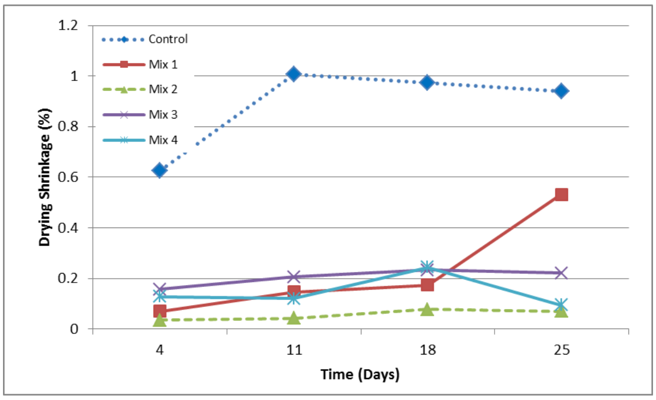


Figure 2. The effect of plastic particles on drying shrinkage

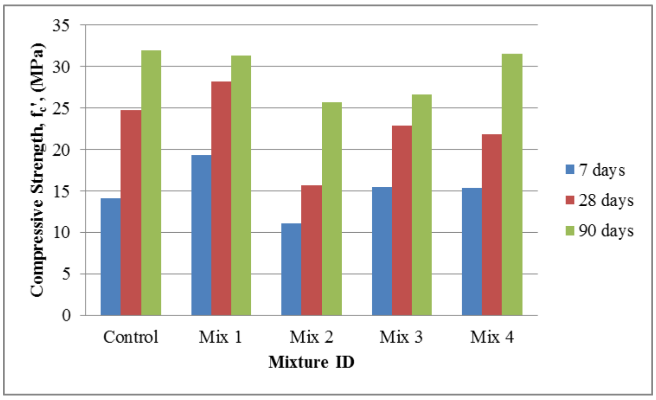


Figure 3. The effect of plastic particles on the compressive strength of SCC mixtures

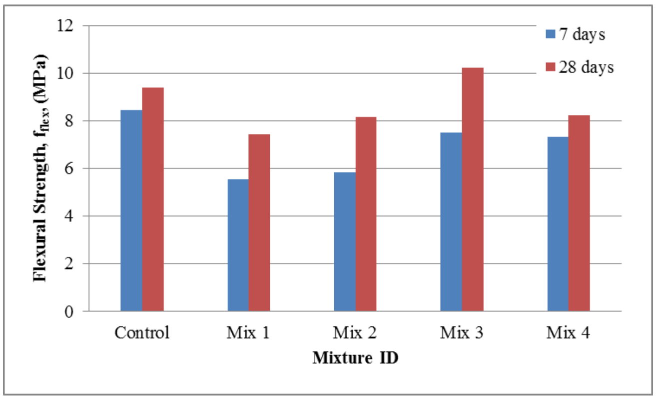


Figure 4. The effect of plastic particles on the flexural strength of SCC mixtures

IV. Conclusion

The results of the presented paper are based on the laboratory experiments of five different SCC mixtures including virgin and recycled high density and low density polyethylene waste particles. The results can be summarized as:

- The additions of plastic particles into the SCC mixtures decrease the flowability
- Virgin or recycled polyethylene waste particles decreases the setting time of SCC mixtures
- The drying shrinkage behavior of SCC mixtures can be improved by the addition of plastic waste granules.
- Addition of virgin or recycled low density or high density polyethylene addition has no impact on the compressive strength value of SCC mixtures.
- Although, the plastic particles has negative effect on flexural strength values of SCC mixtures up to 7 days of curing, after 7 days, flexural strength increases with the addition of plastic particles.

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About Author (s):

[Dr. Nesibe Gözde Özerkan is Associate Researcher in Center for Advanced Materials in Qatar University. She received her B.S. in Civil Engineering from the Cukurova University, Turkey, in 2002. She received her M.S. in January 2006 and Ph.D. in October 2009 from Middle East Technical University, Turkey, both in Civil Engineering. She worked as a graduate teaching and research assistant in the Civil Engineering Department at Middle East Technical University from September 2003 until March 2009. She joined Center of Advanced Materials at Qatar University in September 2009 as a postdoctoral fellow. In 2011, she started to work as a Associate Reseracher/Assistant Professor in the same department. She has extensive experience in mechanics of construction materials, nondestructive evaluation techniques, material science, image processing, construction materials testing procedures, life cycle assessment and recycling. In Center of Advanced Materials, she seeks to develop an environmentally friendly, high performance green concrete that enhances the durability and sustainability of construction.]