Durability studies on SCC Replacing Sand Partially with HIPS Granules

CH. Bala Rama Krishna, P. Jagadeesh

Abstract---* *This investigation is carried out on Self-Compacting Concrete (SCC) replacing sand partially with plastic waste granules of High impact polystyrene (HIPS). Fly ash content of 30% is replaced for cement in the binder content of 497 kg/m3 and HIPS granules with varying percentages from 0-40% are replaced for sand in SCC. Water-to-cementitious content ratio of 0.36 is used in all SCC mixtures. Durability analysis on SCC specimens is conducted by water absorption and sorptivity tests at 28 and 90 days curing age. Fly ash fills the pores at interfacial transition zone and sufficient compaction reduced. So, low volume HIPS replacement up to 30% in SCC has lower porosity. Values are linearly declined up to 30% in the both tests at all curing ages. The smooth surface and spherical shape of HIPS granules leads to weak bonding at cement paste and aggregate interface. Thus porosity increases at high volume replacement starting from 40% due to the less packing density in the concrete matrix. Both water absorption and sorptivity values are higher at 40% replacement compared to SCC mixes contained 0-30% HIPS. E-waste HIPS can be incorporated in concrete to solve issues related to environmental pollution and SCC designed with HIPS up to 30% is more durable.

Keywords:* *Durable, electronic plastic waste, Self-Compacting Concrete, Sorptivity, Water absorption.

1. INTRODUCTION

Durability of concrete indicates the resistance to chemical attack and environmental action; plays a vital role in structures serviceability. Durability depends on the capacity of a liquid penetrate into the concrete and destroy the chemical stability [17]. It depends on the degree of porosity. Porosity is a network of capillary pores and gel pores and this passage allows fluid into concrete. Porosity is measured based on water absorption in concrete [18, 19]. Water absorption (or) Permeability is directly related with the intensity of micro-cracks and pores in matrix [14]. Several researchers suggested the effectiveness of initial curing is an important factor with the addition of mineral admixtures like fly ash with pozzolanic effect in concrete to obtain the better durability [20, 10, 12, 13]. Numerous researchers studied the water absorption in concrete with plastic aggregates [3, 22]. Pozzolonic materials can be used to improve the microstructure of SCC with plastic wastes [21]. Jacob-Vaillancourt and Sorelli [11] expressed no existence of direct correlation between the plastic content used and water absorption. The air-void content in concrete increases water absorption and admixtures addition reduces air content. Water absorption increased with an increase in the percentage replacement of coarse aggregate with e-plastic content in concrete [3, 15, 16]. Coppola et al. [9] produced lightweight concrete replacing fine aggregate with plastic aggregates and identified no water absorption up to 10% sand replacement compared to control concrete. Higher volume replacement of plastic created the more pores in concrete. Ruiz-Herrero et al. [22] reported exponential increment in porosity started from 20% of polyethylene and PVC aggregates at 28 days curing period. Sorptivity is also an index for durability to identify the transportation process of moisture through capillary suction into pores of concrete [16, 23]. Sorptivity with e-waste HIPS as coarse aggregate replacement showed a declined trend in values increasing curing age. In general, sorptivity and water absorption results resemble same trend line [16]. Electronic waste HIPS can be used for fine aggregate replacement up to 30% in concrete [6-8, 24, 25]. The objective in this work is to investigate the durability properties of SCC with HIPS as fine aggregate. Water absorption and sorptivity of SCC were studied replacing cement and sand with fly ash and e-waste HIPS respectively.

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2. SCC EXPERIMENTAL STUDY

2.1. Materials

OPC 53 Grade Cement satisfying the BIS specifications 12269-1987 was used. Specific gravity and water absorption of coarse aggregate were 2.7 and 0.3% respectively. Coarse aggregate passed aggregates from 10mm and 12 mm were mixed in 60:40 ratios. Sand passed from 4.75 mm was used. Specific gravity and water absorption of the sand are 2.6 and 1% respectively. High impact polystyrene (HIPS) size ranging from1.18-3 mm with a specific gravity of 1.04 was used. HIPS aggregate was smooth in surface texture and spherical in shape. Class F Fly ash from NTTPS Vijayawada was used and specific gravity was 2.2. Tap water was mixed in concrete. Sulphonated naphthalene polymer based super plasticizer Fosroc Conplast SP430 and Fosroc Viscosity Modifying Agent were used.

2.2. Mix Proportions

SCC was developed with cementitious content of 497 kg/m^3 and water/binder ratio of 0.36. 30% fly ash was replaced for cement by weight and different % of HIPS by volume was replaced for sand respectively. Coarse aggregates were 28.08% of 12mm and 18.72% of 10mm (by Weight). Sand used was 54.13% by Volume and replaced with HIPS aggregate ranging from 10-40%. M_{30} grade SCC

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with 30% fly ash was considered as the reference mix to examine durable properties.

2.3. Test procedure

2.3.1. Test of water absorption on SCC specimen

Specimens of size 100 × 100 × 100mm were prepared to determine water absorption in SCC. Water absorption test was performed at the age of 28 days according to ASTM C642-13 as shown in figure 1. The specimens were immersed in water up to 28 days. Air dried specimens were placed at 100^0C in an oven until they obtained constant weight (x in Kg). Again specimens were kept in water and weighed the dried specimens (y in Kg) at various intervals of time according to ASTM code. As shown in equation 1, the water absorption (%) was calculated.

Water absorption (%) = [100*(y-x)]/x (1)

Figure 1 Specimens of SCC with HIPS granules in the water filled tank

2.3.2. Sorptivity test of SCC concrete

According to ASTM C1585 – 13, Sorptivity measures the rate of water absorption with the change in mass of concrete sample at different time intervals when one surface only is in touch with water surface up to the depth of 3–5 mm. Capillary suction of water is high at initial time of contact. 100mm diameter and 50mm depth of cylindrical specimens were sealed with the plastic tape except the bottom surface. Dry weights were measured. Submerge the specimen in container touching 3-5 mm of surface with tap water. Note the time and record the mass change of specimen from initial contact with water to different time intervals mentioned in ASTM. The sorptivity was calculated as shown in equations 2 and 3 and tested as shown in figure 2 and figure 3.

$$I = m_t/(a.d) \quad \rightarrow (2)$$

$$S = I/t^{0.5} \quad \rightarrow (3)$$

where,

m_t = change in mass of specimen (gm) w.r.t time(sec),

I = Water absorption per unit surface area (mm),

a = area of specimen exposed (mm^2),

S = sorptivity coefficient ($mm/min^{0.5}$),

d = density of water (g/mm^3) and,

t = weight measured time period(min).

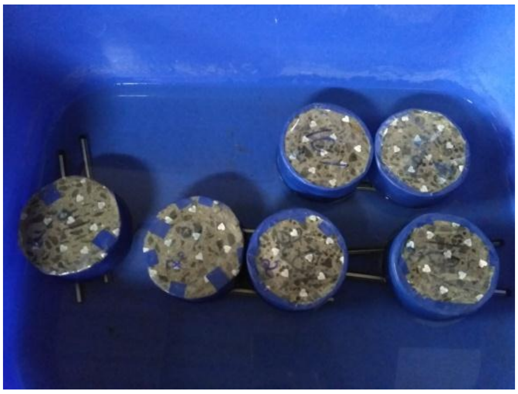

Figure 2 SCC specimens during Sorptivity test

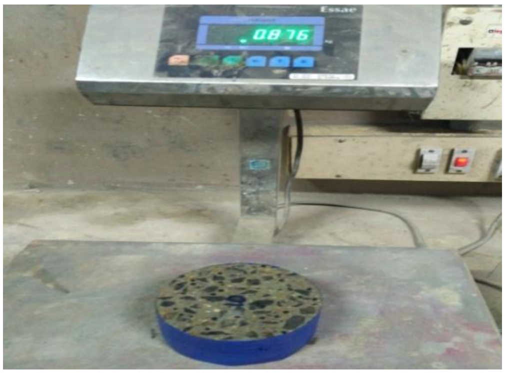

Figure 3 Specimen weighing for sorptivity test

3. RESULTS AND DISCUSSION

3.1. Water absorption of specimens with HIPS aggregate

Water absorption of specimens at the curing periods of 28 days and 90 days are mentioned in Figure 4. As shown in table1 according to the acceptance criteria CEB-FIP 1989, water absorption reduced with an increase of HIPS replacement. Since the values were ranging from 3%-5%, all SCC mixes with 0-40% HIPS performed average in water absorption at 28 days. Water absorption increased after 30% replacement of HIPS and reduced up to 30% HIPS replacement compared to reference SCC. Though fly ash acted as filler at interface in matrix, poor bonding existed between the cementitious paste content and HIPS aggregate. SCC with HIPS showed water absorption of 3.53%, 3.3%, 3.11%, and 4.96% for 10%, 20%, 30%, and 40% replacement respectively. Water absorption up to 30% of HIPS replacement showed better performance than reference concrete having absorption value was 3.89. The main reason for water ingress reduction was due to hydrophobic nature of HIPS and similarly water absorption nature of fly ash in SCC. This combined balancing effect of filling all pore structure reduced the water absorption in SCC. SCC compacted well filling almost all pores during its flow in casting. Since SCC contained more binder content including fly ash and different aggregates including HIPS ranging from 12mm-150µ size particles, it possesses less porosity due to different gradations existed in SCC. Good compaction is also a reason of reduction in the water absorption. In this test, the pozzolanic activity of fly ash highly resisted the water absorption at 90 days curing age.

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All the values showed good performance up to 30% HIPS and obtained the similar reduction trend of 28 days curing. Fly ash formed high C-S-H gel connecting chains in concrete matrix. But the connectivity was disturbed at HIPS high volume replacement since HIPS resisted hydration inhibiting water movement. Up to 30% replacement, HIPS had negligible negative effects in concrete chemistry. But at the high volume addition of HIPS aggregate, porosity increased due smooth texture of HIPS and also spherical compared to natural sand. Though the water absorption was higher with 40% HIPS, the value was less than 5 %. HIPS resists water and can be replaced up to 30%. Further high replacement increased absorption due to the availability of more plastic per unit area. This disintegrated the cohesiveness and less packing density of concrete led to low durability of SCC.

Table 1 CEB-FIP (1989) acceptance criteria for absorption

% of Water Absorption	Durability performance
Less than 3 %	Good
3 %–5 %	Average
Greater than 5 %	worse

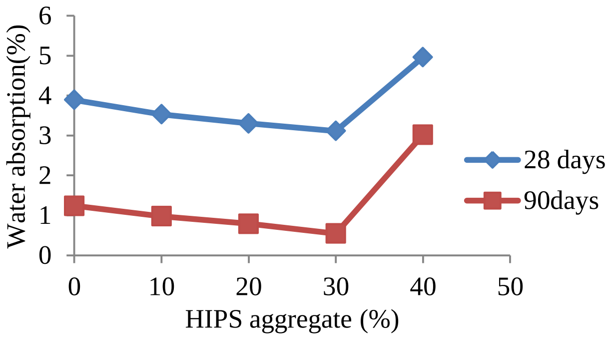

Figure 4 Water absorption (%) at different curing periods of SCC specimens

3.2. Sorptivity performance of SCC specimen with HIPS aggregate

Water absorption rate at the age of 28 days and 90 days are mentioned in figure 5. Values found were reduced from 0%-30% HIPS replacement for fine aggregate. Reduction in sorptivity values up to 30% HIPS at all ages was due to the sufficient compaction in SCC, hydrophobicity of HIPS at surface and pozzolanic action of fly ash in SCC. Pore structure reduced with a continuing gradation evolved among all the aggregates in matrix. Pozzolanic activity of fly ash helped in bonding at ITZ filling voids though HIPS smooth surface has poor bonding. The capillary suction reduced water ingress at longer duration due to more free water existed for hydration and that repelled further water ingress into concrete. Sorptivity values with 0-30% HIPS replacement obtained were ranging 0.766-0.439 mm/√hr at 28 days curing and 0.369-0.156 mm/√hr at 90 days curing respectively. Both the values of sorptivity and water absorption exhibited the same trend line of reducing absorption. Sorptivity values were less than 6% at all ages and were reduced with increment in the curing period. According to the criteria mentioned in table 2, SCC mixes were excellent in sorptivity in all curing periods. SCC with HIPS is more durable compared to reference SCC concrete.

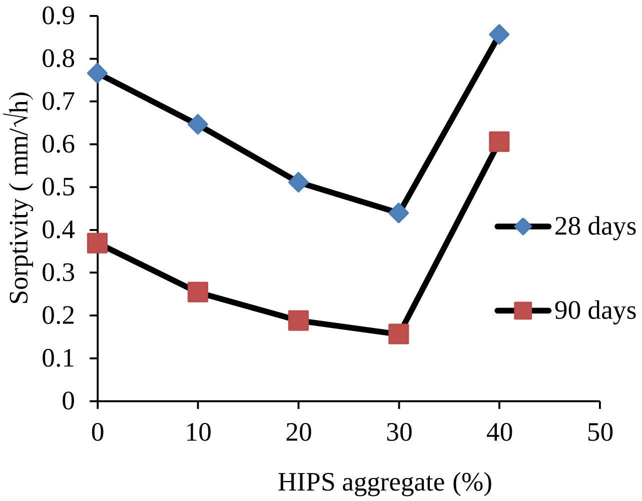

Figure 5 Sorptivity of SCC w.r.t HIPS aggregate (%) at different age

Table 2 Acceptance criteria presented by Kaliyavardhan Senthil kumar [21].

Sorptivity limits (mm/√hr)	Durability Performance
<6	Excellent
6 - 10	Good
10 – 15	Poor
> 15	Worse

4. CONCLUSION

The combined effort of fly ash and HIPS current in improving durability of SCC was clearly visible in this investigation. Following are the conclusions drawn from this investigation:

1) Sufficient compaction attained in SCC due to continuous gradation existed in matrix. HIPS reduced porosity occupying the micro pores. HIPS aggregate has better resistance to water absorption due to the hydrophobic nature.

2) Sorptivity and water absorption showed similar declination trend line at all curing ages. Reduction of water absorption was observed up to 30% replacement, but water ingress was higher at high volume HIPS replacement. It was observed up to 40% replacement, HIPS resisted water ingress according to the ASTM limitations.

3) Reduction in water absorption was also due to the absorbed water in pores repulsion towards the further water movement at longer periods. This action restricts the hydration process creating weak zone at ITZ.

4) Smooth surface and spherical shape of HIPS leads to poor bonding at interface, creates micro cracks and pores with an increment in HIPS replacement. And also availability of more amounts of HIPS granules per unit volume creates high porosity.

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5) SCC with HIPS aggregate up to 30% replacement exhibited good durability in performance. SCC developed with electronic plastic waste protects the structure against environmental affects and protects environment solving disposal issues, reducing emissions, conserving natural resources and energy.

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