Strength and Durability assessment of binary blended Self-Compacting Concrete replacing partial sand with electronic plastic waste

CH. Bala Rama Krishna, P. Jagadeesh

Abstract: ***This work is aimed to examine the strength and durability properties of Self-Compacting Concrete (SCC) replacing fine aggregate partially by volume with e-waste High impact polystyrene (HIPS) granules. In addition, Cement is replaced with fly ash in the optimized binder content of 497 kg/m3 using 0.36 water-to-binder ratio in all SCC mixtures. Compressive strength is studied at 28 and 90 days curing age. Durability tests of SCC such as water absorption and sorptivity are investigated at the age of 28 and 90 days with varying fine aggregate replacement up to 40% at an interval of 10%. The increase in HIPS up to 30% replacement shows a linear declination in the reported values of water absorption, and sorptivity tests at all curing periods. Reduction of compressive strength is minimal at all ages with an increment in the volume of HIPS replacement up to 30%. For SCC mixtures, all test values are within the permissible limits. Different particle sizes of aggregates in SCC achieved continuous gradation. In addition, fly ash contributed its effort acting as filler and holds good bonding at interfacial transition zone. Hence, the reduced porosity helps in improvement of durability properties. This investigation is aided in identifying the excellent durability properties with the both cement and sand replacement by fly ash and e-waste aggregate respectively. Replacing e-waste HIPS as fine aggregate in SCC serves as an eco-friendly multipurpose solution. It compensates the disposal problem, conserves natural resources, and reduces energy, emissions, dead load and cost of concrete production.***

Keywords: ***Durability, e-waste, HIPS aggregate, Self-Compacting concrete, Sorptivity, water absorption.***

I. INTRODUCTION

Durability of concrete is the ability to resist chemical attack and environmental action, maintaining the engineering properties and plays a vital role in structure's serviceability. It depends on the capacity of a liquid to penetrate the microstructure; introduces reacting molecules and destroy the concrete's chemical stability [22]. Degree of porosity is an indication of Water absorption and porosity is measured based on water saturation in microstructure of concrete.

Pore structure forms a network of interconnected capillary pores and passage allows fluid involving hydration process [23, 24]. Even though many techniques can be followed to estimate the pore structure, easy methods suitable to find in field conditions should be adopted. Permeability is closely related with the pore structure in the concrete matrix, the intensity of micro-cracks at interfacial transition zone and in paste itself [19].

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Temperature and duration of curing are the main factors for pore structure.The effectiveness of initial curing becomes more important when mineral admixtures like fly ash are used as partial substitution for cement in concrete. Several researchers suggested effective initial curing is required for mineral admixtures like fly ash to derive better performance of concrete with promising pozzolanic effect [25]. Pozzolonic materials improve the microstructure of SCC developed with plastic wastes [26]. Several researchers evaluated the capacity of water absorption on concrete specimens with plastic aggregates to avoid the steel corrosion [3, 27]. Jacob-Vaillancourt and Sorelli [18] explained no direct correlation existed between the amount of plastic aggregate and water absorption. The highest air-void content in concrete was the reason for the lowest water absorption and the addition of admixtures possibly reduces air content affecting the hydrophobicity of plastic aggregate. Water absorption increased exponentially in concrete with an increase in the percentage replacement of coarse aggregate with e-plastic content [3, 21]. The water absorption with 10%-50% HIPS varied 3.07%-4.55% respectively compared to the control concrete which was having 2.66%. The higher resistance in water ingress is observed with the lower water absorption [21]. Coppola et al. [9] replaced sand with plastic aggregates to produce lightweight foam concrete and found no absorption up to 10% sand replacement compared to reference concrete. But 117% water absorption was found at 50% sand replacement. Higher volume replacement of plastic created the higher amount of porosity. Ruiz-Herrero et al. [27] reported approximately 200% and 140% higher porosity with 20% of polyethylene and PVC aggregates were identified at 28 days curing period. Recently, sorptivity is also considered as one of the index for durability and it involves in the transportation process of moisture into pores through capillary suction [21, 28]. Total volume of both capillary and gel pores in concrete can be estimated weighing the water uptake of concrete specimens from soaking during sorptivity test. It is a quick and easy method to determine surface absorption rate. Sorptivity with HIPS as coarse aggregate exhibited declined values with an increase of curing period. The resistance to water ingress was higher with the lower sorptivity values. In general, sorptivity test results were in line with water absorption results [21] though there is no need to exist such kind of exact relation. Fly ash enhances workability and strength improving microstructure in SCC [15-17]. Electronic plastic waste HIPS can be replaced as coarse aggregate up to certain extent though strength reduces [20] and HIPS can be replaced for fine aggregate up to 30% in concrete but strength reduces [6-8].

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The main objective of this study is to examine strength and durability properties of SCC with e-waste as fine aggregate. Compressive strength, Water absorption, porosity and sorptivity of Self-Compacting concrete were determined replacing cement and sand with fly ash and e-waste HIPS respectively.

II. EXPERIMENTAL STUDY

A. Materials

Cement: 53 Grade Cement was used in concrete according to the BIS specifications 12269-1987.
Coarse aggregate: Aggregates passed from 10mm and 12 mm were mixed in the ratio of 60:40. Specific gravity and water absorption of the coarse aggregate are 2.70 and 0.30% respectively.
Fine aggregate: River sand with maximum size of 4.75 mm was used. Specific gravity and water absorption of the sand are 2.60 and 1.00% respectively.
Plastic: Electronic plastic waste namely, High impact polystyrene (HIPS) of varying size 1.18-3 mm with a specific gravity of 1.04 was replaced fine aggregate partially. The surface of HIPS aggregate is smooth in surface texture and spherical in shape as shown in Figure 1.
Fly Ash: Class F Fly ash belonged to NTTPS Ibrahimpatnam, Vijayawada was replaced for cement. Specific gravity of fly ash was 2.2.
Water: Potable tap water at room temperature was mixed for developing SCC according to BIS 456-2000 recommendations.
Super Plasticizer: A sulphonated naphthalene polymer based Fosroc Conplast SP430 super plasticizer was used.
VMA: Fosroc Viscosity Modifying Agent was used. Percentage of dry material in SP and VMA was 40%.

Figure 1: High impact polystyrene granules

B. Mix Proportions

SCC having cementitious content of 497 kg/m^3 was produced replacing cement partially with 30% fly ash by weight and sand with different % of HIPS by volume respectively. Coarse aggregate used were 28.08% of 12mm by Weight and 18.72% of 10mm by Weight. Fine aggregate content was 54.13% by Volume and replaced with 10- 40% HIPS aggregate. The water to binder (cement + fly ash) ratio was 0.36 for all mixes. SCC with only replaced 30% fly ash was considered as the reference mix. M_{30} grade SCC was used to determine durable properties.

C. Test procedure

a. Water absorption test

All SCC cube specimens of size 100 × 100 × 100mm were prepared to determine the water absorption. As shown in Figure 2, the water absorption test at the curing age of 28 days was performed according to ASTM C642-13. The specimens after demoulding were immersed in water until the age of 28 day. The specimens were air dried and placed in an oven at 100^{0}C until a constant weight (x in Kg) is obtained. Specimens were again immersed in water and saturated surface dried specimens were weighed (y in Kg) at specific intervals of time mentioned in ASTM standards. Thus, the water absorption (%) according to the equation was calculated as shown in equation 1.

$$\text{Water absorption (\%)} = [100*(y-x)]/x \quad (1)$$

Figure 2: SCC specimens with HIPS in water tank

b. Sorptivity test of concrete

This test was performed according to ASTM C1585 − 13 to determine the rate of absorption of water measuring the change in mass of a concrete specimen with respect to time when only one surface is submerged in water container to a depth of 3–5 mm. Test procedure is conducted until constant sorptivity value is obtained [29]. Capillary suction of water in unsaturated concrete is high in initial contact of water. The cylindrical specimens of dimensions 100mm diameter and 50mm depth were sealed with plastic cover except bottom surface. Weights of samples were measured. Place the support at the specimen's bottom and fill the container with tap water until 3-5 mm of concrete bottom surface. Start the stop watch and record the mass change from initial contact with water to different time periods. 60sec, 5min, 10min, 20min, 30min and 60 min for initial rate of absorption and secondary absorption rate is considered at time intervals mentioned in ASTM. The sorptivity was calculated as shown in equations 2 and 3 and tested as shown in Figure 3.

$$I = m_t/(a.d) \quad (2)$$
$$S = I/t^{0.5} \quad (3)$$

where,
I = Water absorption per unit concrete surface area (mm),
m_t = the change in mass of specimen (grams) w.r.t time(sec),
a = exposed area of specimen (mm^2), and
d = density of water (g/mm^3).
S = sorptivity coefficient (mm/min$^{0.5}$)
t = time at weight measured (min)

Figure 3: Sorptivity test with SCC specimens during test and weighing with exposed bottom surface

c. Compressive strength

Compressive strength of SCC specimens (150mm x 150mm x 150mm) was determined according to the IS: 516 (Reaffirmed in 2013). The cube specimen was placed in the machine with the axis of SCC specimen aligned carefully with the centre of thrust of the spherically seated plates. The continuous load was gradually applied without any vibration at a rate of approximately 14 N/mm^2/min until the specimen failed and the corresponding load was recorded. Compressive strength of SCC cube specimen was obtained dividing the failure load by the cross-sectional area. Compressive strength was determined at curing ages of 28 days and 90 days.

III. RESULTS AND DISCUSSION

a. Influence of HIPS aggregate on water absorption of SCC specimens

The water absorption test values of SCC specimens after curing of 28 days and 90 days are shown in Figure 4. The water absorption with HIPS aggregate reduced with an increase in percentage replacement. Acceptance criteria according to CEB-FIP, 1989 is shown in Table I. Since the values for all mixes were in between 3%-5%, it was observed that SCC with 0-40% HIPS was average in water absorption at the age of 28 days. Water absorption increased abruptly after 30% replacement of HIPS and reduced up to 30% HIPS replacement compared to SCC without HIPS. Because of Poor bonding existed between cementitious paste content and HIPS even though fly ash acted as filler at ITZ particularly, water absorption values were average but satisfactory. The water absorption values of SCC specimens with HIPS at the age of 28 days were 3.53%, 3.3%, 3.11%, and 4.96% for 10%, 20%, 30%, and 40% respectively. Interestingly, the water absorption with e-waste up to 30% replacement showed better performance than reference concrete having absorption value was 3.89%. The reason for reduction in water absorption was due to water repellent nature of HIPS and water absorption nature of fly ash. This combination balanced the water content in SCC for hydration filling all pore structure. Good compaction of concrete also reduces the water absorption. SCC filled almost all pores during its flow in casting since it 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. In this test, the pozzolanic activity highly resisted the water absorption in longer curing periods i.e., 90 days. All the values obtained were showing good performance up to 30% HIPS and the similar reduction trend followed the age of 28 days. Since fly ash was used, it formed more C-S-H gel all over the matrix with connecting chains. Though HIPS had no action in concrete chemistry, it just acted as inert and resisted hydration inhibiting water movement. Until 30% replacement, all these negative effects were negligible. But the high volume addition of HIPS aggregate increased the porosity of concrete due to spherical shape and smooth texture of HIPS compared to natural sand. Though the water absorption of SCC with 40% HIPS was higher, the value was within the permissible limit (<5 %). HIPS resists water up to 30% and further replacement due to availability of more plastic per unit area disintegrate the cohesiveness and packing density of concrete that also leads to bleeding during mixing the concrete and effects durability severely.

Table I: Acceptance criteria according to CEB-FIP, 1989 [5]

Water Absorption (%)	Performance
<3 %	Good
3 %–5 %	Average
>5 %	Poor

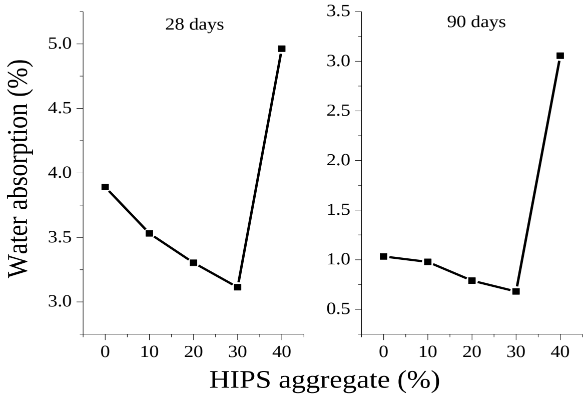

Figure 4: Water absorption (%) of SCC mixes with HIPS aggregate (%) at different curing periods

b. Influence of HIPS aggregate on Sorptivity of SCC specimen

The rate of water absorption at the curing periods of 28 days and 90 days are shown in Figure 5. The initial rate of water absorption is shown in figure shown and it satisfied the criteria mentioned in ASTM C1585-13. Sorptivity values were reduced from 0%-30% replacement of fine aggregate with HIPS aggregate. And also values were reduced with increasing the curing period. According to the acceptance criteria mentioned in the table 2, values are observed to be excellent in durability class (< 6%) at all ages of curing. Reduction in sorptivity values up to 30% HIPS at all ages was primarily due to sufficient compaction attained, with the enhanced rheology of SCC by pozzolanic material fly ash and e-waste HIPS.

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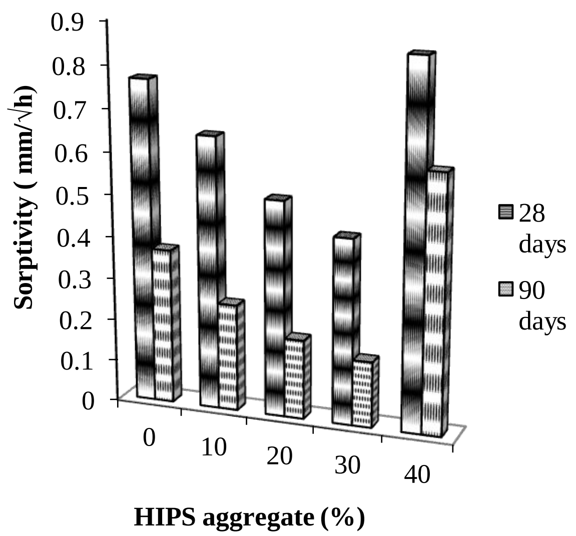
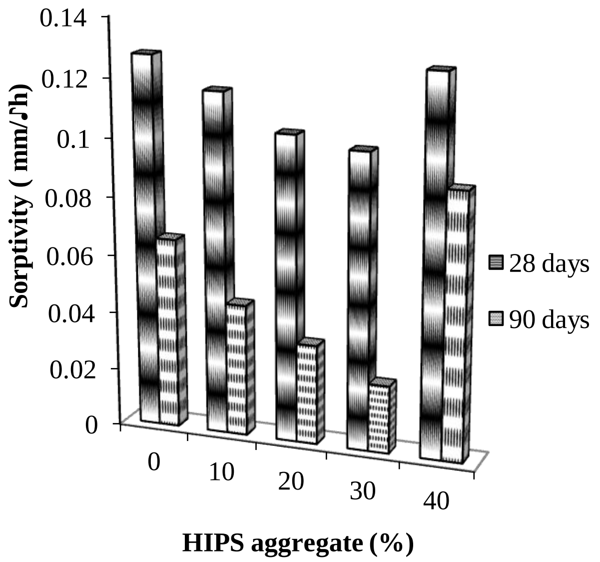
Pore structure was highly reduced with different gradation evolved among the aggregates in matrix. And also, pozzolanic activity of fly ash helped in bonding at ITZ filling voids though HIPS smooth surface has poor bonding. At longer duration, the capillary suction reduced water ingress since already water existed for hydration process that is still remained due to hydrophobic nature of HIPS. And there is no possibility of further water ingress into concrete. According to K. Senthil kumar [21], sorptivity values were measured at 1 hour time period as shown in Figure 5a. And they were ranging 0.766-0.439 mm/√h at 28 days curing and 0.369-0.156 mm/√h at 90 days curing from 0-30% replacement respectively. According to R. Lakshmi [29], sorptivity values were measured until consecutive constant values obtained and the values were shown in Figure 5b. All the values obtained were in the ranges mentioned in Table II. Both sorptivity and water absorption showed the similar trend of reducing absorption. SCC incorporated with HIPS is more durable though strength reduces compared to reference SCC concrete.

Table II: Acceptance criteria suggested by Alexander et al. [30,31]

Durability index	Sorptivity limits (mm/√h)	Acceptance Criteria
Excellent	<6	Highly acceptable
good	6 – 10	Acceptance
poor	10 – 15	Remedial measures required for acceptance
worse	> 15	Rejected



(a) Sorptivity at 1hr time period



(b) Sorptivity at constant value

Figure 5: Sorptivity of SCC with respect to % variation of HIPS aggregate at different curing age

c. Effect of HIPS aggregate on compressive strength of SCC specimen

Compressive strength values of 28 and 90 days are shown in Figure 6. Addition of e-waste HIPS for fine aggregate replacement in SCC mix reduced the strength. Strength reached target strength of M30 grade concrete up to 30% HIPS replacement. The reduction was linear up to 40% replacement but strength from 40% HIPS was abruptly declined. The microstructure of matrix was weak at ITZ due to porosity created by smooth surface of HIPS. But the microstructure was strengthened with fly ash filling voids up to 30% replacement. Fly ash also absorbed the excess water available in the pore structure of matrix. Since HIPS restricted the water movement in SCC due to hydrophobic nature, it was additional to fly ash in delaying the hydration process. Thus SCC attained the compressive strength in longer duration.

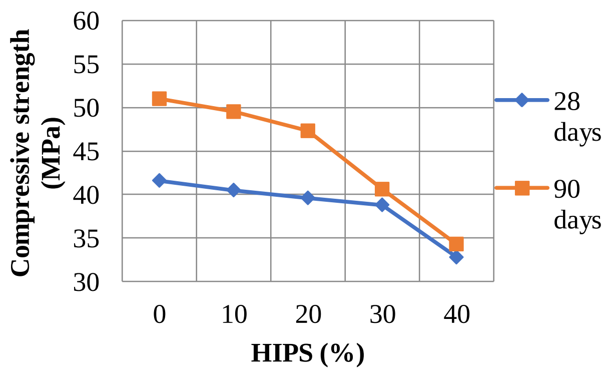


Figure 6: Compressive strength variations with different % of HIPS aggregate

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IV. CONCLUSION

The following conclusions are drawn with the effects of electronic waste HIPS granules on self-compacting concrete:

- HIPS granules showed better resistance to water ingress up to 30% replacement due to hydrophobic nature but percentage of absorption increased at high volume replacement of HIPS.
- Porosity reduced up to 30% replacement of HIPS at all curing ages due to sufficient compaction available with enhanced rheology. Spherical shape of fly ash and HIPS filled all voids between aggregates obtaining continuous gradation among the matrix
- Since HIPS size, shape and inert nature reflects fine aggregate, HIPS took part in replacing sand for producing flow-able concrete. Due to smooth surface and spherical shape of HIPS, poor bonding at ITZ creates micro cracks and pores with increment in HIPS replacement. And availability of high amount of HIPS per unit volume also creates high porosity.
- Sorptivity also showed similar trend line of water absorption at all curing ages. The capillary suction of water ingress reduced due to smooth surface existed by the spherical particles of fly ash and HIPS.
- HIPS aggregate helped SCC efficiently to achieve excellent durable performance. It can be replaced for sand up to 30% with no hesitation for producing eco-friendly, economical and durable SCC.

REFERENCES

1. ASTM C642-13, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, ASTM International, West Conshohocken, PA, 2013, www.astm.org
2. ASTM C1585-13, Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic—Cement Concretes, ASTM International, West Conshohocken, PA, 2013, www.astm.org
3. Akram A, Sasidhar C, Pasha K.M, "E-Waste Manage by Utilization of E-Plastics in Concrete Mixture as Coarse Aggregate Replacement," Int. J. Innov. Res. Sci. Eng. Technol. 2015, 4.
4. BIS 2386 (Part I- IV)-1963, Methods of Test for Aggregates for Concrete, Bureau of Indian Standards, New Delhi, India, 1963.
5. CEB-FIP, "Diagnosis and Assessment of Concrete Structures— State of Art Report," CEB Bull, Vol. 192, 1989, pp. 83–85.
6. Ch. Bala Rama Krishna And P. Jagadeesh, "Influence Of Admixtures On Plastic Wastes In An Eco-Friendly Concrete A Review," International Journal Of Civil Engineering And Technology, 8(6), 2017, 388–397.
7. CH. Bala Rama Krishna and P. Jagadeesh, "Fresh and Hardened Properties of Self-Compacting Concrete Replacing Fine Aggregate with High Impact Polystyrene Plastic Granules, International Journal of Civil Engineering and Technology," 9(12), 2018, pp. 831–838
8. CH. Bala Rama Krishna and P. Jagadeesh, "Compressive strength evaluation of eco-friendly concrete replacing sand partially with High impact polystyrene," International Journal of Civil Engineering and Technology, 9(1), 2018, 865–870.
9. Coppola B. Courard L, Michel F, Incarnato L, Scarfato P, Di Maio L, "Hygro-thermal and durability properties of a lightweight mortar made with foamed plastic waste aggregates," Constr. Build. Mater. 170, 2018, 200–206.
10. EFNARC, 2005. Specification and guidelines for self-compacting concrete. English ed.Norfolk, UK: European Federation for Specialist Construction Chemicals and Concrete Systems.
11. IS12269-1987 Specification for 53 grade ordinary Portland cement. Bureau of Indian Standards, New Delhi, India.
12. IS 456-2000 Plain and reinforced concrete—code of practice. Bureau of Indian Standards, New Delhi, India
13. IS 10262:2009 Concrete mix proportioning—guidelines. Bureau of Indian Standards, New Delhi, India
14. IS 516-2004 Indian standard code of practice—methods of test for strength of concrete. Bureau of Indian Standards, New Delhi, India.
15. J. Guru Jawahar, C. Sashidhar, I.V. Ramana Reddy, J. Annie Peter, "Micro and macro level properties of fly ash blended self compacting concrete," Materials and Design, 46, 2013, 696–705.
16. J. Guru Jawahar, C. Sashidhar, I.V. Ramana Reddy, J. Annie Peter, "Effect of coarse aggregate blending on short-term mechanical properties of self compacting concrete," Materials and Design, 43, 2013, 185–194.
17. J. Guru Jawahar, C. Sashidhar, I.V. Ramana Reddy J, Annie Peter, "Design of cost-effective M 25 grade of self compacting concrete, Materials and Design," 49, 2013, 687–692.
18. Jacob-Vaillancourt, C.; Sorelli, L, "Characterization of concrete composites with recycled plastic aggregates from postconsumer material streams," Constr. Build. Mater. 182, 2018, 561–572.
19. G. De Schutter and K. Audenaert, "Evaluation of water absorption of concrete as a measure for resistance against carbonation and chloride migration," Materials and Structures, vol. 37, no. 273, 2004, pp. 591–596.
20. Senthil Kumar, K. and Baskar, K., "Development of Ecofriendly Concrete Incorporating Recycled High Impact Polystyrene From Hazardous Electronic Waste," J. Hazard. Toxic Radioact. Waste., Vol. 19, No. 3, 2015, 04014042.
21. K. Senthil Kumar, P. V. Premalatha, and K. Baskar, "Evaluation of Transport Properties of Concrete Made With E-Waste Plastic," Journal of Testing and Evaluation, ASTM, 45 (5), 2016, 1849-1853.
22. P. K. Mehta and P. J. M. Monteiro, Concrete: Microstructure, Properties and Materials, 2006, McGraw-Hill, NewYork, NY, USA.
23. M. Ramli and A.A. Tabassi, "Effects of polymer modification on the permeability of cement mortars under different curing conditions: a correlational study that includes pore distributions, water absorption and compressive strength," Construction and Building Materials, vol. 28, no. 1, 2012, pp. 561–570.
24. N. Shafiq and J. G. Cabrera, "Effects of initial curing condition on the fluid transport properties in OPC and fly ash blended cement concrete," Cement and Concrete Composites, vol. 26, no.4, 2004, pp. 381–387.
25. C. Tasdemir, "Combined effects of mineral admixtures and curing conditions on the sorptivity coefficient of concrete," Cement and Concrete Research, vol. 33, no. 10, 2003, pp. 1637–1642.
26. Sadeghi-Nik, Aref, Lotfi-Omran, Omid, "Estimation of compressive strength of self-compacted concrete with fibers consisting nano-SiO2 using ultrasonic pulse velocity," Constr. Build. Mater. 44, 2013, 654-662.
27. Ruiz-Herrero J.L, Nieto D.V, Lopez-Gil A, Arranz A, Fernandez A, Lorenzana A, Meriono S, De Saja J.A, Rodriguez M.A, "Mechanical and thermal performance of concrete and mortar cellular materials containing plastic waste," Constr. Build. Mater. 104, 2016, 298–310.
28. W. P. S. Dias, "Reduction of concrete sorptivity with age through carbonation," Cement and Concrete Research, vol. 30, no. 8, 2000, pp.1255–1261.
29. R. Lakshmi and S. Nagan, "Investigations on durability characteristics of e-plastic waste incorporated concrete." Asian journal of civil engineering, (Building and Housing), 12(6), 2011, 773-787.
30. Alexander, M. G., Ballim, Y., and Maketchnie, J. R., "Guide to Use of Durability Indexes for Achieving Durability in Concrete Structures," Research Monograph No. 2, Collaborative Research by Universities of Cape Town and Witwatersrand, Cape Town, South Africa, 1999.
31. Alexander, M. G., Ballim, Y., and Maketchnie, J. R., "Concrete Durability Index Testing Manual," Research Monograph No. 4, Collaborative Research by Universities of Cape Town and Witwatersrand, Cape Town, South Africa, 1999.