STRENGTH AND PERMEATION RESISTANCE OF CEMENTS MADE FROM LOCAL WASTE MATERIALS

FOLAGBADE Samuel Olufemi

Department of Building, Obafemi Awolowo University, Ile-Ife, NIGERIA.
Email: samuelfolagbade@yahoo.com
Tel: 08140969822

Abstract
Supplementary cementitious materials (SCMs) would reduce the cost and embodied carbon-dioxide (eCO_2) content of concrete. Hence, using compressive strength, void content, initial surface absorption after 10 minutes (ISA) and sorptivity, this paper assessed the effect of rice husk ash (RHA) and sawdust ash (SDA) on the strength and permeation resistance of concrete at equal water/cement ratios and 28-day strengths of 35 and 40 N/mm^2. These properties were determined to standards. Results revealed that while the supplementary cementitious materials (SCMs) reduced strength and permeation resistance at early ages, the disparity reduced with increasing curing age such that they become comparable with Portland cement (PC) concrete at later ages. At equal 28-day strengths, the blended cement concretes have higher permeation resistance than PC concrete and this increased with increasing content of the SCMs. Since concrete is specified, in practice, on the basis of the 28-day strengths, RHA and SDA have the propensity to produce concrete with good strength and durability performance at reduced cost and eCO_2 content.
Keywords: blended cement, compressive strength, concrete durability, permeation resistance, pozzolan, supplementary cementitious materials, waste materials.

1. Introduction

Wastes, whether domestic, industrial or agricultural, constitute nuisance to the environment. Hence, they must be properly managed. A common way of managing waste is to put them in landfills. However, wastes in landfills would lead to construction and health problems. This is because landfills are made-up grounds that would lead to settlement of building if the foundation is not taken to a firm bearing stratum. Also, the leaching of chemicals in these wastes would lead to the contamination of ground and ground water and therefore health problems.

Another important environmental issue is sustainability which entails preserving the environment from deterioration. Also germane to sustainability issue is global warming which has been linked with emissions of oxides of nitrogen (NOx), sulphur dioxide (SO_2) and carbon dioxide (CO_2) into the atmosphere. Carbon dioxide is the most devastating of these greenhouse gases because of its link with global warming. Hence, towards reducing the emissions level, the meeting of some countries in Kyoto, Japan in 1997 led to the development of some guidelines in Marrakesh, Morocco in 2001. These were with the aim of reducing the emissions level between 2008 and 2012 by 5%. A follow-up to this was the Doha Amendment of 2012 which extended the protocol from 2013 to 2020 with the hope of achieving an emissions reduction level of 18% by 2020.

Furthermore, the production of one tonne of Portland cement is associated with the emission of about one tonne of carbon dioxide into the atmosphere (The Concrete Industry Sustainable Construction Forum, 2009). This therefore makes the reduction in the consumption of Portland cement in concrete construction an emission mitigating strategy. Hence, the application of sustainability principle in construction led to the use of cements from waste materials. These alternative cement are by-products of industrial wastes such as fly ash (FA), ground granulated blast-furnace slag (GGBS), silica fume (SF), metakaolin (MK) etc. which are already recognised by cement and concrete standards like BS EN 197-1, BS EN 206-1 and BS 8500-1&2 and used in the developed world and by-products of agricultural wastes such as sawdust ash (SDA), rice husk ash (RHA), corncob ash, cassava peels ash etc. which have been attested to as being suitable for the production of strong and durable concrete (Nedhi *et al*., 2003; Ogunbode & Akanmu, 2012; Akinwumi & Aidomojie, 2015; Raheem *et al*., 2017). However, these by-products of agricultural wastes which are currently not recognised by standards nor used in concrete production. Hence, they are being regarded, in this paper, as cements from local waste materials.

Supplementary cementitious materials (SCMs) have intrinsic hydraulicity. This is because they cannot develop useful strength on their own but as partial replacement for Portland cement (PC) content of concrete. Also, while PC undergoes hydration reaction, the SCMs undergo pozzolanic reaction. Pozzolanic reaction is the reaction between the SCMs and the $Ca(OH)_2$ generated by the hydration reaction of PC. Pozzolans with high amount of amorphous silica is characterised by high pozzolanic reaction, formation of additional calcium silicate hydrates and improved concrete performance (Zhang & Malhotra, 1996; Rasoul *et al*., 2017). Also, since the SCMs will have to wait for $Ca(OH)_2$ to be generated by PC, pozzolanic reaction is a delayed reaction. Hence, the SCMs are generally characterised by low early-age strength and durability performance. However, due to continuous pozzolanic reaction with increasing curing age, they would contribute to later-age strength and durability performance of concrete. In order to provide more information on the suitability of cements made from local waste materials to support the strength and durability performance of concrete, this paper assessed the strength and permeation resistance of concrete made with RHA and SDA. This is due to the availability of rice husk and sawdust wastes in large quantities. It is also the belief of this paper that the acceptance and patronage of RHA and SDA will engender more research that will encourage the use of other by-products of local waste materials. Furthermore, the use of RHA and SDA in concrete would reduce the need for landfill sites and therefore contribute to solving the disposal problem and proper management of sawdust and rice husk wastes.

Amorphous RHA is obtained by calcining rice husk at temperatures below 800^{o}C (Abalaka, 2013) and with about 100 million tonnes of rice husk or 20 million tonnes of RHA available per year (Jongpradist *et al*., 2018), enough RHA would be available for use in concrete. Since RHA is calcined at temperatures far lower than that of PC (about 1700^{o}C), its use would reduce the embodied carbon dioxide content of concrete. The partial replacement of PC with RHA, at equal water/cement ratios, would reduce the compressive strength of concrete with increasing content (Madandoust *et al*., 2011; Marthong, 2012). Like every pozzolan, while RHA will reduce strength development at early ages, the pozzolanic reaction with increasing curing age will result in concrete with strength comparable with that of the conventional concrete at later ages (Abalaka, 2013). The use of RHA will also reduce the porosity and increase the resistance of concrete to chemical attack from deleterious materials (Chindaprasirt *et al*. 2007, Thomas, 2018). Hence, for good concrete strength and durability performance, a range of 10-40% has been suggested for the RHA content of concrete (Jongpradist *et al*., 2018); Abalaka, 2013; Ganesan *et al*., 2008; Safiuddin *et al*., 2010; Chao-Lung *et al*., 2011; Ettu *et al*., 2013).

Sawdust is an agricultural waste found in great quantity in many countries of the world. Sawdust waste is in abundance (Oluoti *et al*., 2014). Hence, it is readily available. Also, like RHA, sawdust ash (SDA) would reduce concrete performance at early ages and improve concrete performance at later ages (Obilade, 2014; Folagbade & Aluko, 2019). Hence, in order to ensure good results, Folagbade & Aluko (2019) suggested an SDA content of not more than 20% in concrete.

The durability of concrete (ability of concrete to resist deterioration while in use) would depend on its resistance to permeation. This is because if the deleterious materials are prevented from entering concrete, the durability of concrete would be preserved. Permeation resistance of concrete could be assessed, among others, by its porosity and resistance to sorption (sorptivity) and surface absorption. This is because the resistance of concrete to permeation depends on the porosity (volume of voids) of concrete (Scivener & Nemati, 1996; Claisse *et al*., 2001; Li *et al*., 2019). Sorptivity is a measure of water movement by capillary attraction which would occur even in minute pores in concrete. The initial surface absorption measures the resistance of the surface of concrete against water penetration (Neville, 2012; BS 1881-208, 1996). Also, initial surface absorption after ten minutes (ISAT-10), according to BS 1881-208 (1996) is sufficient for assessing the resistance of the surface of concrete to a pressure of water equivalent to that of driving rain. Concrete is expected not only to be strong and durable but also to be cheap and environmentally compatible. Also, to dissuade the negative status (inferiority, low quality, second rated) erroneously associated with cements made from waste materials and popularise their use, this paper investigated the strength and permeation resistance of RHA and SDA blended cement concrete using compressive strength, ISAT-10, sorptivity and void content of concrete.

2. Materials and Methods

The cements used in this investigation were Portland cement (PC, 42.5 strength class), rice husk ash (RHA) and sawdust ash (SDA). Using an average of 400-800^{o}C used by Jongpradist *et al*. (2018), RHA was calcined to a maximum of 600^{o}C and left at this temperature for about 5 hours. Sawdust ash (SDA) was calcined at a temperature of 500^{o}C. The ashes were cooled to room temperature and sieved with 75µm sieve. The oxide compositions of PC, RHA and SDA are presented in Table 1. Sand was used as fine aggregates and 19 mm granite chippings were used as coarse aggregates.

Concrete was designed using the Building Research Establishment Design Guide (Teychenne *et al*., 1997) and investigated at up to 30% contents of RHA and SDA (in line with previous studies) at the water/cement ratios of 0.35, 0.50 and 0.65 using a free water content of 210 kg/m^3. Mapefluid N200, conforming to BS EN 934-2 (2009), was used as superplasticiser during mixing to achieve a consistence level of S2 characterised by a nominal slump of 50-90 mm (BS EN 206-1, 2000). Concrete was prepared to BS EN 12390-2 (2000), cast and covered with polythene for about 24 hours before being demoulded and cured in water. Compressive strength, void content, initial surface absorption and sorptivity tests were carried out on the hardened concrete specimens. Compressive strength was determined in accordance with BS EN 12390-3 (2002) using 100 mm cubes at the curing ages of 7 and 28 days. Void content was determined at 28 days in accordance with ASTM C642 (2006) using Equation 1.

$$\text{Void content (\%)} = \frac{B-A}{B-C} * 100 \qquad (1)$$

where A = Oven-dried mass at 105±5^{o}C.

B = Saturated mass after immersion and boiling.

C = Apparent mass after suspension in water.

Initial surface absorption after 10 minutes (ISA-10) was determined at 28 days in accordance with BS 1881-208 (1996) using 150 mm concrete cubes oven-dried to constant mass at 105±5^{o}C. The specimens were cooled to room temperature in a desiccator and subjected to a pressure of 200 mm head of water as shown in Fig. 3. The tap was turned off after 10 minutes to remove the applied water head and the average distance moved by water along the capillary tube in a minute, over three readings, was obtained and multiplied by the calibration factor of the tube determined in accordance with BS 1881-208 (1996). The ISAT-10 values for the specimens were obtained using Equation 2.

$$ISAT\text{-}10 = N_{10} \times C_f \quad (2)$$

where
ISAT-10 = Initial surface absorption at 10 minutes after water first touched the surface of concrete.
N_{10} = Number of scale divisions moved, in a minute, after the tap was turned off 10 minutes after water first touched the surface of concrete.
C_f = Calibration factor of capillary tube.

Sorptivity at 28 days were obtained in accordance with ASTM C1585 (2013). Concrete specimens 100 mm in diameter and 50 mm thick were oven-dried to constant mass at about 105±5°C, cooled to room temperature in a dessicator containing silica gel and waxed on the side. The upper end of the specimen was covered with a loose plastic sheet attached with masking tape to allow the air entrapped in the pores to escape from the concrete pores while at the same time preventing water loss by evaporation. The initial mass of the specimen was obtained and the other uncovered end was placed on supports in water. The level of water was maintained at 3-5 mm above the top of the support throughout the duration of the test. The test was conducted over 6 hours and the cumulative change in mass at specific intervals was determined. This involved removing the specimen from water, cleaning the test surface with a dampened paper towel to remove water droplets and measuring the weight before placing the sample in water to continue the test. Using Equation 3, the cumulative change in mass at 1 minute, 5 minutes, 10 minutes, 20 minutes, 30 minutes, 1 hour, 2 hours, 3 hours, 4 hours, 5 hours and 6 hours were used to obtain the respective cumulative absorption values.

$$i = \frac{\Delta m}{A * \rho} \quad (3)$$

where i = cumulative water absorption,
Δm = cumulative change in mass due to water absorption,
A = cross-sectional area of test specimen, mm^2 and
ρ = density of water.

Using Darcy's Law expressed in Equation 4 (Hall, 1989), the cumulative absorption values were plotted against the square root of test times and sorptivity (the initial rate of water absorption) was obtained as the slope of the line that best fits the plot.

$$i = S * t^{0.5} \quad (4)$$

where S = sorptivity
t = test time in seconds

3. Results and Discussion

3.1 Characteristics of supplementary cementitious materials

A good concrete is expected to be strong, durable, cheap and environmentally compatible. Hence, to ensure their acceptability and use, the SCMs should be able to contribute to ensuring these. Table 1 compares some characteristics (basic oxides composition, particle shape, fineness and embodied carbon dioxide (eCO_2) content) of RHA and SDA that are germane to the strength, durability, cost and environmental compatibility of concrete with that of Portland cement (PC), fly ash (FA), silica fume (SF) and metakaolin (MK).

Table 1: Properties of Portland cement and rice husk ash

	PC	FA	SF	MK	RHA	SDA
CaO, %	63.2	3.2	0.4	0.0	2.7	9.5
SiO_2, %	19.7	52.0	96.6	57.6	86.4	63.0
Al_2O_3, %	4.7	26.0	0.7	38.9	1.7	8.3
Fe_2O_3, %	3.2	10.1	0.2	0.6	0.8	3.9
Total acidic oxide, %		88.1	97.5	97.1	88.9	75.2
Particle shape	Angular	Spherical	Spherical	Angular	Spherical	Spherical
Blaine fineness, m^2/kg	395	388	15000	2588	NA	NA
eCO_2 content, kg/tonne[1]	930	4	14	300	NA	NA

Table 1 shows that the SCMs are characterised by low lime (CaO) contents which confirms why their pozzolanic reaction is delayed. However, with a total acidic oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$) contents greater than 70%, the SCMs (and especially RHA and SDA) are good pozzolans. Also, their higher silica (SiO_2) and/or alumina (Al_2O_3) contents would guarantee the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) which are strength enhancing hydration products.

Particle shape has implication for the permeation resistance and cost of concrete. Spherical, as opposed to angular, particle shape is characterised by a good packing ability within the concrete matrix and at the interfacial zones between the cement paste and the aggregates. This would result in a dense microstructure and therefore improved resistance to permeation. Also, a spherical particle shape would reduce water demand and therefore reduce superplasticiser dosage and cost of concrete. The fineness is a measure of the specific surface available for hydration reaction. Hence, the higher the fineness, the higher the nucleation sites available for hydration reaction and the higher the reactivity of the cement. Furthermore, the lower the eCO_2 content, the higher the environmental compatibility of the SCMs and the blended cement concrete. The foregoing therefore shows that the partial replacement of PC with the SCMs would produce a strong, durable, cheap and environmentally compatible concrete.

3.2 Compressive strength of concrete at equal water/cement ratios

Tables 2 and 3 present the compressive strengths and strength factors (ratio of strength of blended cement concrete to that of PC concrete at same age) of concretes at the curing ages of 7 and 28 days at different contents of RHA and SDA and water/cement ratios. As expected, compressive strength increased with increasing curing age due to formation of strength enhancing hydration products and reduced with increasing water/cement ratio and content of the SCMs due to reduction in cement and PC contents respectively. Also, the strength factors were respectively lower at the curing age of 7 days than at 28 days. The low values of the strength factors at 7 days would be due to reduction in the PC content (dilution effect) leading to reduction in the content of $Ca(OH)_2$ and delay in pozzolanic reaction. However, due to continuous pozzolanic reaction, the disparity in strength with that of PC reduced with increasing curing age. This shows that RHA and SDA would support later-age strength development.

Table 2: Compressive strength of RHA blended cement concrete

Mix Combination	w/c	Compressive strength, N/mm²		Strength factor, %			
		d7	d28	d7	d28	d28 Average	d28 Disparity
	0.35	47.0	67.5	100	100		
100PC	0.50	33.0	49.5	100	100	100	-
	0.65	25.0	38.0	100	100		
	0.35	39.0	60.5	83.0	89.6		
90PC+10RHA	0.50	27.5	44.5	83.3	89.6	89.6	10.4
	0.65	20.5	30.0	82.0	89.5		
	0.35	33.5	54.5	71.3	80.7		
80PC+20RHA	0.50	24.0	40.0	72.7	80.8	80.2	19.8
	0.65	17.5	30.0	70.0	79.0		
	0.35	28.5	47.0	60.6	69.6		
70PC+30RHA	0.50	21.0	35.0	63.6	70.7	70.0	30.0
	0.65	15.5	26.5	62.0	69.7		

Table 3: Compressive strength of SDA blended cement concrete

Mix Combination	w/c	Compressive strength, N/mm²		Strength factor, %			
		d7	d28	d7	d28	d28 Average	d28 Disparity
	0.30	54.0	72.5	100	100		
100PC	0.50	31.0	48.0	100	100	100	-
	0.70	22.0	34.0	100	100		
	0.30	43.0	63.0	79.6	86.9		
90PC+10SDA	0.50	24.5	42.0	79.0	87.5	87.1	12.9
	0.70	17.5	29.5	79.5	86.8		
	0.30	37.0	57.0	68.5	78.6		
80PC+20SDA	0.50	21.5	38.0	69.4	79.2	78.6	21.4
	0.70	15.0	26.5	68.2	77.9		
	0.30	29.5	46.5	54.6	64.1		
70PC+30SDA	0.50	17.0	31.0	54.8	64.6	64.5	35.5
	0.70	12.0	22.0	54.5	64.7		

Table 2 shows that a unit replacement of PC with RHA reduced the 28-day compressive strength of concrete by 1.04, 0.9 and 1.0% at the total replacement levels of 10, 20 and 30% respectively. Hence, a unit replacement of PC with RHA would reduce the 28-day compressive strength of concrete by an average of 0.98%. Similarly Table 3 shows that a unit replacement of PC with SDA reduced the 28-day strength of concrete by 1.29, 1.07 and 1.18% at the total replacement levels of 10, 20 and 30% respectively. this shows that a unit replacement of PC with SDA would reduce the 28-day strength of concrete by an average of 1.18%. The comparison of the strength performance shows that RHA would perform better than SDA. This is probably due to the higher silica content of RHA (Table 1).

3.3 Permeation resistance of concrete at equal water/cement ratios

3.3.1 Effect of RHA on the void content and initial surface absorption of concrete

Table 4 presents the void content and initial surface after 10 minutes (ISA-10) of concretes and their factors (ratio of void content or ISA-10 of blended cement concrete to that of PC concrete at same age) of concretes at the curing age of 28 days at different contents of RHA and water/cement ratios. As expected, void content and ISA-10 increased with increasing water/cement ratio and content of RHA due to reduction in cement and PC contents respectively. It is also expected, due to the filling of the pores within the concrete matrix with hydration products, that void content and ISA-10 would reduce with increasing curing age.

Table 4: Void content and ISA-10 of concrete

Mix	w/c	Void content, %				ISA-10 x 10^{-2}, ml/mm^{2}s^{-1}			
		d28	Factor	Mean	Disp.[1]	d28	Factor	Mean	Disp.[1]
100PC	0.35	11.24	100	100	-	36.50	100	100	-
	0.50	14.96	100			48.14	100		
	0.65	22.05	100			66.40	100		
90PC+ 10RHA	0.35	12.46	110.9	110.9	10.9	39.84	109.1	109.0	9.0
	0.50	16.61	111.0			53.12	110.3		
	0.65	24.45	110.9			71.38	107.5		
80PC+ 20RHA	0.35	13.26	118.0	118.1	18.1	43.16	118.2	117.6	17.6
	0.50	17.67	118.1			56.44	117.2		
	0.65	26.08	118.3			78.02	117.5		
70PC+ 30RHA	0.35	14.12	125.6	125.9	25.9	44.82	122.7	123.1	23.1
	0.50	18.83	125.9			59.76	124.1		
	0.65	27.82	126.2			81.34	122.5		

1. Disparity with respect to PC

Table 4 shows that a unit replacement of PC with RHA increased the 28-day void content of concrete by 1.09, 0.91 and 0.86% at the total replacement levels of 10, 20 and 30% respectively. Hence, a unit replacement of PC with RHA would reduce the 28-day void content of concrete by an average of 0.95%. Similarly, a unit replacement of PC with RHA increased the 28-day ISA-10 of concrete by 0.90, 0.88 and 0.77% at the total replacement levels of 10, 20 and 30% respectively. This shows that a unit replacement of PC with RHA would reduce the 28-day ISA-10 of concrete by an average of 0.85%.

3.3.2 Effect of SDA on the sorptivity of concrete

Table 5 presents the sorptivity of concretes and their factors (ratio of sorptivity of blended cement concrete to that of PC concrete at same age) of concretes at the curing age of 28 days at different contents of SDA and water/cement ratios. As expected, sorptivity increased with increasing water/cement ratio and content of SDA due to reduction in cement and PC contents respectively. It is also expected, due to the filling of the pores within the concrete matrix with hydration products, that sorptivity would reduce with increasing curing age. Also, a unit replacement of PC with SDA increased the 28-day sorptivity of concrete by 1.19, 1.10 and 1.18% at the total replacement levels of 10, 20 and 30% respectively. Hence, a unit replacement of PC with SDA would increase the 28-day sorptivity of concrete by an average of 1.16%.

Table 5: Sorptivity of concrete

Mix combination	w/c	Sorptivity of concrete x 10^{-3}, mm/√s			
		d28	Factor	Mean	Disparity
100PC	0.30	22.0	100	100	-
	0.50	27.5	100		
	0.70	39.0	100		
90PC+10SDA	0.30	24.5	111.4	111.9	11.9
	0.50	31.0	112.7		
	0.70	43.5	111.5		
80PC+20SDA	0.30	26.9	122.3	121.9	21.9
	0.50	33.5	121.8		
	0.70	47.4	121.5		
70PC+30SDA	0.30	29.9	135.9	135.4	35.4
	0.50	37.0	134.5		
	0.70	53.0	135.9		

3.4 Permeation resistance of concrete at equal 28-day strengths

In practice, concrete is designed and specified on the basis on the 28-day cube compressive strength (f_{cu}) and not on the basis of water/cement ratio. In order to assess the permeation resistance of the blended cement concretes at equal 28-day strengths, Tables 6 and 7 present the permeation resistance of PC and blended cement concretes at the 28-day strengths of 35 and 40 N/mm^2. The tables show that equal strength with the PC concrete were achieved by the blended cement concretes at lower water/cement ratios and the water/cement ratios decreased with increasing content of RHA and SDA. Also, at equal strengths with PC concrete, the blended cement concretes have lower void content, ISA-10 and sorptivity values and therefore higher resistance to permeation than PC concrete and the resistance improved with increasing content of RHA and SDA. With increasing strength, the water/cement ratios are further reduced resulting in higher permeation resistance.

Table 6: Void content and ISA-10 of concrete at equal strengths

Mix combination	35 N/mm^2			40 N/mm^2		
	w/c	Void content, %	ISA-10, ml/mm^2s^{-1}	w/c	Void content, %	ISA-10, ml/mm^2s^{-1}
100PC	0.70	25.2	74.0	0.61	19.8	60.9
90PC+10RHA	0.63	23.2	68.7	0.55	18.8	58.7
80PC+20RHA	0.56	20.6	64.1	0.50	17.7	56.4
70PC+30RHA	0.50	18.8	59.8	0.43	16.1	52.0

Decreasing water/cement ratio connotes increasing total cement content which would also affect the cost and eCO_2 content of concrete. However, due to the comparatively lower cost of the SCMs (as a result of being by-products of wastes) and lower eCO_2 contents (as a result of their lower calcination temperatures), the possibility that the cost and eCO_2 content of the blended cement concrete would reduce with increasing content is very high. Nonetheless, the actual cost, fineness and eCO2 content of these by-products of agricultural wastes would only be known when they are produced and bagged for sale like Portland cement.

Table 7: Sorptivity of concrete at equal strengths

Mix combination	35 N/mm^2		40 N/mm^2	
	w/c	Sorptivity x 10^{-3}, mm/√s	w/c	Sorptivity x10^{-3} , mm/√s
100PC	0.67	37.6	0.59	32.5
90PC+10RHA	0.59	36.5	0.52	32.4
80PC+20RHA	0.54	36.3	0.47	32.2
70PC+30RHA	0.43	33.9	0.37	31.7

4. Conclusion

In order to provide more information on the suitability of cements made from local waste materials, this paper investigated the strength and permeation resistance of RHA and SDA binary cement concretes and the following conclusions have been drawn.

- Due to the continuous pozzolanic reaction, RHA and SDA would produce concrete with comparable strength with PC concrete if appropriately proportioned. However, equal strengths with PC concrete would be produced by the blended cement concretes at lower water/cement ratios.
- Any desired strength can be achieved by the blended cement concrete. It will only require low or very low water/cement ratios.

- RHA and SDA would produce concrete with higher resistance to permeation than PC concrete at equal strengths. Also, at equal strengths, the higher the contents of the SCMs, the higher the permeation resistance and therefore the durability of concrete. Hence, there is the need for the interplay of other factors like cost and environmental compatibility before the actual limit to their content could be established.

Hence, the use of cements made from waste materials have the propensity to contribute to strength development, improve the permeation resistance and durability of concrete, reduce the cost of concrete and make concrete more environmentally compatible while at the same time help in the management of these wastes. However, to ensure an optimal use, there is the need for more research efforts and investment in the production of these SCMs in order to be able to accurately establish their eCO_2 contents, specific surface and costs. This is because it is only when they are produced and sold on commercial basis that we can be sure of their actual characteristics.

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