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Pavement construction using self-compacting concrete: Mechanical properties

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ABSTRACT

This experimental study assessed the strength properties of some selected Portland limestone cement for self-compacting concrete in pavement construction. Self-compacting concrete offers many advantages in the construction world but its utilization in pavement construction is low. To achieve the aim of this research, four brands of grades (42.5 and 32.5) of the cement were used. Cement brands A, B, C and D were used in SCC samples tagged as SCC 1, 2, 3 and 4 respectively. To this end, rheological tests were carried out using the L-Box, V-Funnel and slump cone. Additionally, mechanical properties (compressive, split tensile and flexural strength) of the hardened concrete were evaluated. The compressive and flexural tests were determined at 3, 7, 14, 21 and 28, 56 and 91 days of curing. SCC 4 with Brand D showed the highest strength at 3 days but had the lowest at 28 days and 91 days. However, SCC 1 with brand A showed the highest strength at maturity. Additionally, the result showed that the percentage difference in the compressive strength of the SCC 1 and the other mixes were 27.6%, 27.7% and 40.7% while 18.1%, 27.5% and 42.1% increment was recorded for the flexural strength of SCC 1, SCC 2, and SCC 3 respectively. However, SCC 4 had the best rheological properties, though the lowest strength. A positive strong correlation was recorded for the mechanical properties of the SCC mixtures. Moreover, the relationship between the mechanical properties and age followed a logarithmic trend with R^2 value that ranges from 0.86 to 0.977 which established the robustness. Ultimately, the result revealed that SCC 1 with brand A proved to be the most suitable for SCC in rigid pavement construction.

1. Introduction

Concrete according to Naik (2008) is one of the most utilized construction materials and is second only to water as the most utilized substance on the planet Gambhir (2005). There are several types and applications of concrete in the construction industry. Self – Compacting concrete (SCC) is a special type of high strength and high performance concrete used for construction purpose that requires no mechanical vibration, it is highly flow able (Naik, 2008; Kurita and Nomura, 1998). Hence, it has revolutionized concrete placement Tande and Mohite (2007). The use of (SCC) in civil engineering applications has been on rise for more than 20 years, it has been adopted in the construction of bridges, tunnel and structures Ramadan and Haddad (2017) but recent trend is now stirring towards its application in road construction as asserted by Thomas and Pasko (1998). The same author avows that in assessing the trend, past and future of highway SCC is the future in road construction industry due to its enormous advantages. SCC could be an appropriate choice to increase the performance and consistency of concrete and is an economical engineering choice for concrete construction, especially concrete pavements (Khayat and Assaad, 2002). The best practices for airport Portland cement concrete pavement construction for rigid airport pavement are defined in the IPRF (2003). The research stipulated that concrete should be designed to obtain minimum flexural strength of 4.1 MPa for airport pavement at 28 days and an acceptable design modulus of rupture (DMR) for bending strength at 90 days. The permissible

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compressive strength must exceed 30.3 MPa (FAA, 2014). Correspondingly, recent trend now showed that the usage of SCC in the construction of rigid pavements such as traffic lanes and bridges, high-ways and airports 'runways) are now evidence in major area (Ramadan and Haddad, 2017) .Strength is one of the most important attribute of concrete pavement and concrete structures and the same applies to SCC. The strength of concrete largely depends on the quality and quantity of cement as it is the strength giver in concrete (Adewole et al., 2014). Generally, there are three cement grades: grade 33, grade 43, and grade 53 which are also referred to as cement strength classes 32.5MPa, 42.5MPa and 52.5MPa respectively (BS EN 197-1, 2011).There are different types of cement used in concrete production based on the composition. BS EN 197-1 (2011), Mathur et al. (2014) and Hodhod and Abdeen (2010) worked on the strength properties of some selected brands of OPC. Portland limestone cement CEM II is a brand of portland composite cement that comprises of a major secondary constituent (Limestone) added to OPC (BS EN 197-1, 2011). Apart from the major constituent (clinker and gypsum), 6-35% of limestone has been added to reduce the cost of production and to make grinding easy Hawkins et al. (2003). Based on the addition of limestone the strength properties of the cement may be lower than OPC and this may also affect the mechanical strength properties of concrete Adewole et al. (2014). There exists a dearth of literature on the strength grouping of Portland limestone cement in SCC production for pavement construction. Hence, this study assessed the strength properties of some selected grades and brands of Portland limestone cement for SCC in pavement construction.

2. Methodology

2.1. Experimental material

Locally available aggregates of size 4.75mm for fine aggregate were used in the experimental work. The minimum required cement content for airfield concrete pavement is a function of the maximum size of aggregates (MSA). The MSA for this study was 19 mm, which requires minimal cement content. Portable water free from toxins and deleterious materials were used all through the research. Mix ingredients, and proportions were according to EFNARC (2002). Four selected brands of Portland limestone cement (CEM II/A-L and CEM II/B-L) available in Nigeria open market conforming to ASTM (2013) were used in the research. One unit plain SCC mixture was designed at a w/c ratio of 0.38 with fine and coarse aggregate prepared according to rational mix design method by Ozawa et al. (1995). The four cement brands 1, 2, 3 and 4 were used in the SCC production and hence tagged as SCC 1, 2, 3 and 4 respectively. Brand A is Grade 42.5 while the other brands are 32.5. The rheology of the concrete was assessed using the slump cone, V-funnel and the L-box according to the specification of (ASTM, 2013; EFNARC, 2002). In a bid to attain the desired workability using Ozawa et al. (1995) approach several trials were made varying the water cement ratio and super plasticizer dosage while the mass of fine and coarse aggregate were kept constant. CONPLAST super-plasticizer according to EFNARC (2006) specification was used in improving the workability. 150mm×150mm×150mm and 100mm x 400mm x 100mm mould were used for both compressive and flexural test respectively with oil smeared on the inside of the mould to avoiding sticking after obtaining a uniform and consistent mixture. The concrete was mixed and cured in accordance with ASTM (2011).

3. Result and discussion

From Table 1 brand C had the lowest composition of the alkaline oxides which may have implication on the strength properties as suggested by the same author. From the result of the composition of oxides in the selected brands and grades of cement, brand A had higher calcium oxide than the remaining two brands. This may have implication on the strength and setting time of the cement as suggested. The physical properties are as shown in Table 2. Brand A had the highest compressive strength. The composition of Silicon and aluminum oxide also had strength implication.

Table 1: Chemical composition of the cement brands

Parameters	Brand A	Brand B	Brand C	Brand D
Potassium Oxide	0.34	0.32	0.37	0.35
Silicon Oxide	19.07	21.3	20.05	20.28
Sodium Oxide	0.42	0.54	0.6	0.58
Calcium Oxide	64.52	64.22	63.84	63.79
Iron Oxide	0.72	0.85	0.63	0.94
Magnesiun Oxide	2.2	2.1	1.98	2.02
Manganese Oxide	0.08	0.07	0.02	0.05
Aluminium Oxide	4.96	4.6	4.97	4.51

Table 2: Physical properties of the cements

Cement Brands	Consistency	Initial Setting Time	Final Setting Time	Compressive Strength
Brand A	30	45	395min	46.6
Brand B	30	51	405min	36.7
Brand C	30	55	465 min	34.4
Brand D	30	61	554min	29.8

The result of the setting time (initial and final setting time) were within the specification of IS (1988). Furthermore, the result showed similar attributes with the findings of Sahana (2013) and Sahu and Mishra (2015).

3.1. Rheological properties of the cement brands

Slump flow is an indication of the flow ability of the mix. EFNARC (2002) was used as the acceptable criteria for SCC rheological properties. Brand A's slump flow (T50) was not within the specified range of (2-5 secs) while the other three brands were within this limit (Fig. 3). The four SCC's V-funnel result were satisfactory (within the range of 6-12 secs) according to EFNARC (2002) specification. This showed that the viscosity and filling ability were satisfactory. L-box was used to assess the passing and filling ability of the concrete mix. The result revealed that SCC 1, SCC 2, SCC 3 and SCC 4 result was between the standard specifications (0.8-1) while the L-box result for SCC 2 was out of the specified range (Fig. 1). Ultimately, workability properties showed that only SCC 4 had good rheological properties having satisfied the specification for viscosity (T_{50}), segregation and passing ability using EFNARC (2006) standard. This may be explained by the chemical composition of the cement brands. Brand A and B's calcium oxide which content is higher than brand C, indeed high calcium oxide increases the setting time and hence reduces the workability which may account for the variation in the rheological properties as reflected in the result.

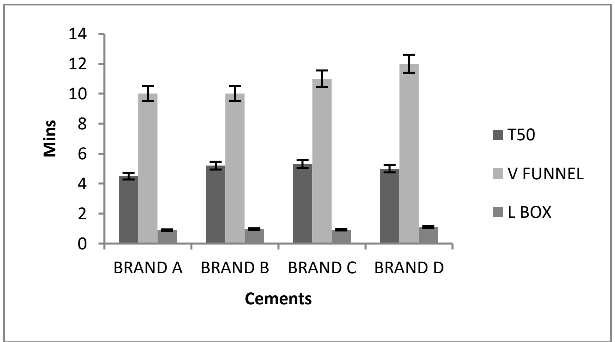

Fig. 1: Rheological properties of the selected brand of cement

3.2. Compressive strength of the SCC mixes

According to Wright (1996), the recommended compressive strength of concrete for pavement construction at maturity should be 27.6KN/mm².

Fig 2 shows the result of the compressive strength of the SCC developed at different curing ages. The result of the analysis showed that SCC 1 with cement brand A acquired that strength at 28 days of curing. This indicated that it is good for rigid pavement construction. The SCC 2, SCC 3 and SCC 4 with the other brands of cement were not able to meet up with the specification for pavement construction at 28 days. The major reason for this could be as a result of the grade of the cement and chemical composition of the cement brand. Brand A and Brand B had higher composition of calcium oxide, aluminum oxide and silica oxide which may invariably affect the percentage of clinker and gypsum as these are the strength giver of cement civil today. However, they satisfied the requirement for reinforced concrete structures. SCC 1 and SCC 4 with brand A and brand C showed a high early strength as indicated in the result while SCC 2 had the lowest (11.35KN). However, at maturity SCC 4 had the lowest compressive strength.

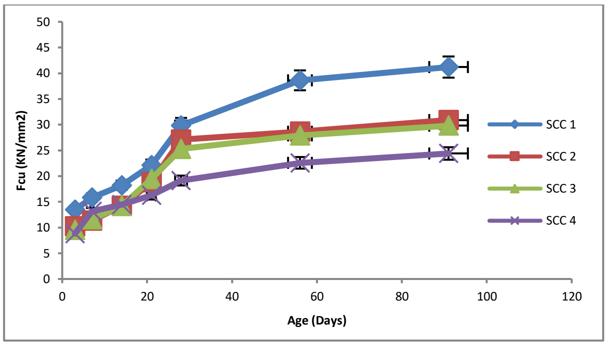

Fig. 2: Compressive strength of the selected brand at maturity

The result showed that only SCC 1 with cement brand A had the specified compressive strength for pavement construction at maturity. Conversely in some developing countries like Nigeria most construction workers tend to buy brand name and not grade as avowed by Adewole et al. (2014) and as such use these lower grades of cement for pavement construction which affects the strength.

The descriptive statistics of the compressive strengths of the four SCC with the selected Portland limestone cement is as seen in Table 3. From the table, the mean, median, standard deviation, the skewness, kurtosis, Jarque-Bera values and their corresponding probability values were also reported. The result of the statistical analysis of the compressive strength after 91 days showed that the mean which is a pointer to the average of the compressive strengths recorded for the four SCC mixes was within the range of 18.47 and 30.60.

The median of the SCC's F_{cu} is within 19.14 to 32.82. However, the explosiveness of the variables which was indicated by the four SCC's standard deviation was far from the mean distribution which is an indicator that the degree of variability of the compressive strength around their mean is high. Additionally, normality test was conducted using the Jarque-Bera statistics and their probability values were also reported. The skewness and the kurtosis indicator revealed that all the compressive strength recorded are positively skewed. Besides, the kurtosis value indicates that all the F_{cu} values are platykurtic.

Table 3: Descriptive statistics of the compressive strength of the SCC samples

	SCC 1	SCC 2	SCC 3	SCC 4
Mean	30.60700	22.10444	21.64000	18.47000
Median	32.82000	27.10000	25.30000	19.14000
Maximum	45.10000	29.80000	29.50000	24.20000
Minimum	13.44000	10.21000	9.550000	8.820000
Std. Dev.	12.41084	8.388480	8.049983	5.581675
Skewness	-0.197973	-0.407248	-0.438463	-0.42886
Kurtosis	1.524810	1.390444	1.503245	1.844480
Jarque-Bera	0.874860	1.220278	1.128479	0.776588
Probability	0.645694	0.543275	0.568793	0.678213
Sum	275.4630	198.9400	194.7600	166.2300
Sum Sq. Dev.	1232.232	562.9328	518.4178	249.2408

However, the correlation statistics as indicated in Table 4 showed that a positive strong relationship was recorded for the compressive strengths of the SCC mix with the selected brands.

Table 4: Correlation of the compressive strength of the selected brands

	SCC 1	SCC 2	SCC 3	SCC 4
SCC 1	1.000000	0.969433	0.979046	0.971270
SCC 2	0.969433	1.000000	0.996920	0.968206
SCC 3	0.979046	0.996920	1.000000	0.979291
SCC 4	0.971270	0.968206	0.979291	1.000000

3.3. Flexural strength of the SCC mixes

The result of the flexural strength of the SCC's is as seen in Fig. 3. Concrete pavement carries load as simple plain non reinforced concrete beam MCAAT (2009). Concrete pavements are classified as rigid because it possesses some degree of beam strength that allows it to span Wright (1996). Flexural strength was evaluated because it is the basic parameter for computing deflection in rigid pavement and it is also used in the structural design of concrete pavement.

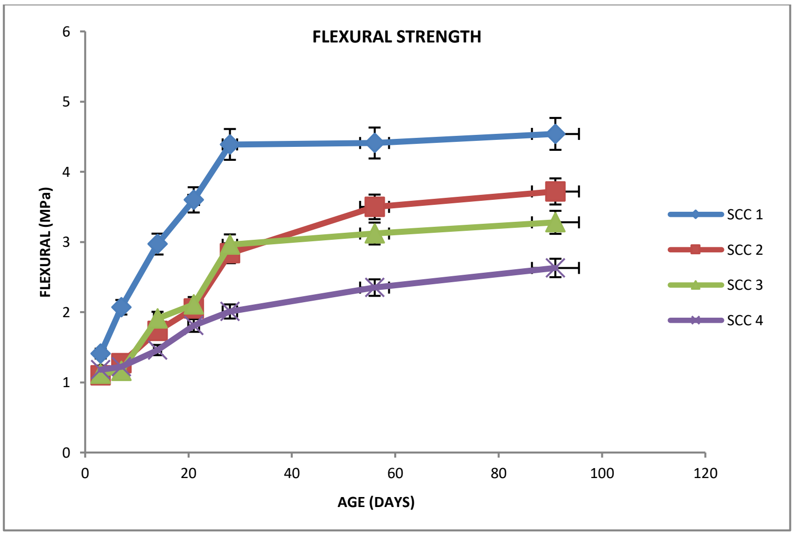

Fig. 3: Flexural strength of the selected brands at maturity

Correspondingly, flexural strength of SCC 1 was the highest and this meet up with the standard specification for rigid pavement as specified by Wright (1996). The result of the flexural strength for SCC 1 also fell within the specified value for airfield rigid pavement according to FAA (2014) and European specifications for high quality JPCP which asserted that the flexural strength value should range from 4.3 to as high as 7.0 Mpa for all rigid pavement applications. SCC 2, 3 and 4 flexural strength was below pavement specification, however, the values are good enough for other structural applications as specified in BS 8110.

3.4. Statistical relationship between the flexural strength of the SCC mixtures

Assessment of the statistical relationship between the flexural strength of the SCC mixtures as shown in Table 5 revealed that the explosiveness of the variables was far from the mean distribution which is an indicator that the degree of variability of the compressive strength around their mean is high. However, SCC 2, SCC 3 and SCC 4 showed a positive platykurtic distribution while only SCC 4 showed a negative platykurtic distribution. This reflected in the strength gained at maturity as seen in Fig. 3. Besides the correlation statistics also showed a strong positive correlation. This means that as the curing age increased the flexural strength also increased while comparing the various SCC mixtures.

Table 5: Descriptive statistics of the flexural strength of the SCC

	SCC 1	SCC 2	SCC 3	SCC 4
Mean	3.175000	2.081667	2.193333	1.671667
Median	3.285000	1.890000	2.010000	1.635000
Maximum	4.610000	3.500000	3.900000	2.350000
Minimum	1.410000	1.100000	1.120000	1.180000
Std. Dev.	1.272348	0.931008	1.077732	0.465679
Skewness	-0.216014	0.479203	0.535288	0.288596
Kurtosis	1.616298	1.838567	2.010805	1.670139
Jarque-Bera	0.525320	0.566867	0.531160	0.525420
Probability	0.769003	0.753193	0.766761	0.768965
Sum	19.05000	12.49000	13.16000	10.03000
Sum Sq. Dev.	8.094350	4.333883	5.807533	1.084283

3.5. Correlation of the flexural strength of the selected brands

The regression analysis of the compressive and flexural strength at the different ages revealed that the best fit for the plot showed a logarithmic trend. Table 6 explains the correlation statistics

The equations governing the trend and the R^2 are as indicated in Table 7 where y is the flexural and compressive strength and x is the age.

Table 6: Correlation

	SCC 1	SCC 2	SCC 3	SCC 4
BRAND_A	1.000000	0.953066	0.939216	0.963215
BRAND_B	0.953066	1.000000	0.995969	0.986267
BRAND_C	0.939216	0.995969	1.000000	0.980307
BRAND_D	0.963215	0.986267	0.980307	1.000000

Table 7: Regression equations

MIX	REGRESSION EQUATION	R SQUARE VALUE
	FLEXURAL STRENGHT	
SCC 1	y = 8.844ln(x) + 0.4846	0.9211
SCC 2	y = 6.622ln(x) + 0.4497	0.8758
SCC 3	y = 6.3604ln(x) + 0.7369	0.9115
SCC 4	y = 4.4679ln(x) + 3.7296	0.9772
	COMPRESSIVE STRENGTH	
SCC 1	y = 10.149ln(x) – 1.3517	0.8624
SCC 2	y = 6.9423ln(x) + 0.2068	0.8831
SCC 3	y = 6.360ln(x) + 0.7369	0.9115
SCC 4	y = 4.4679ln(x) + 3.7296	0.9772

3.6. Split tensile

Tensile characteristics directly affect the initiation of transverse cracking and corner break. The result of the tensile strength for the SCC mixtures followed similar trend with the flexural and the compressive strength (Fig. 4). SCC 1 showed the highest tensile strength throughout the curing age. 30.5% difference was recorded in the tensile strength gained of SCC 1 and SCC 2, however at 91 days of curing, the percentage difference increased to 43.5%.

Nevertheless the higher the age the greater the disparity in the tensile strength value of SCC 1 compared with others. Model predictions for the relationship between the tensile strength and the compressive strength indicate the influence of mix design parameters. However, since the same concrete ingredients were used all through the research the only varied parameter was cement, this is an indication that cements brands and grades affect the tensile properties of SCC mixtures all things being equal. This is also reflected by the result of the compressive strength and the flexural strength.

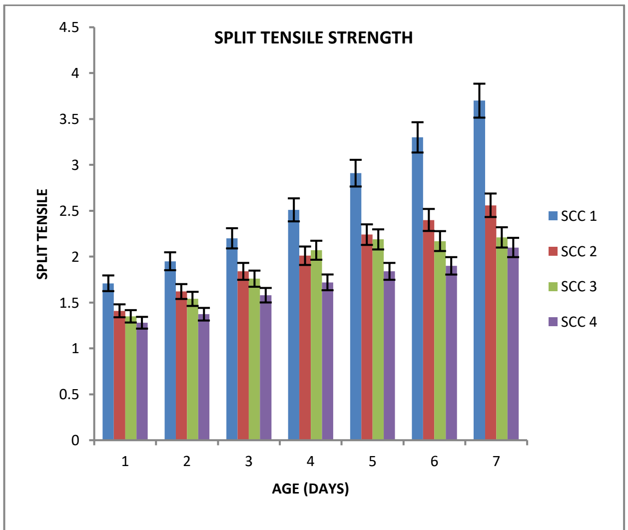

Fig. 4: Split tensile

4. Conclusion

Strength is one of the most important attribute of pavement. The strength grouping showed that SCC 2, SCC 3 and SCC 4 may not be suitable for pavement construction because the flexural strength at 91 days was below 4.5Mpa. However, SCC 1 flexural strength at maturity is adequate for pavement construction. However, SCC 4 possesses better rheological properties than SCC 1, but the mechanical properties of SCC 4 were the lowest according to the V-funnel, L-box and slump flow test. This may be as a result of the calcium oxide which tends to increase the setting time of the concrete.

a. The result of the chemical composition indicated that brand D had the lowest Calcium oxide composition.
b. SCC 1 showed the highest tensile strength throughout the curing age. 30.5% difference was recorded in the tensile strength gained of SCC 1 and SCC 2, however at 91 days of curing, the percentage difference increased to 43.5%. Nevertheless the higher the age the greater the disparity in the tensile strength value of SCC 1 compared with others.
c. The result of the difference in the strength of the SCC 1 and the other mixes showed that 27.6%, 27.7% and 40.7% increment was recorded for the compressive strength of SCC 1, SCC 2, and SCC 3 respectively.
d. The result of the difference in the strength of the SCC 1 and the other mixes showed that 18.1%, 27.5% and 42.1% increment was recorded for the flexural strength of SCC 1, SCC 2, and SCC 3 respectively.
e. However if construction work involves good rheological properties, then brand D may be appropriate. The relationship between the mechanical properties and age followed a logarithmic trend with R^2 value that ranges from 0.86 to 0.977 which establish the robustness.

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References

Adewole KK, Olutoge FA, and Habib H (2014). Effect of nigerian portland-limestone cement grades on concrete compressive strength. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, 8(11): 1199-1202.

ASTM (2011). C1194-03-Standard test method for compressive strength of cylindrical concrete specimens. American Society for Testing and Materials. Philadelphia, USA.

ASTM (2013). C 1621/C 1621M-Standard test method for passing ability of self-consolidating concrete. American Society for

Testing and Materials, WSDOT Materials Manual, Pennsylvania, USA.

BS EN 197-1 (2011). Cement Part 1: Composition, specifications and conformity criteria for common cements, British Standards Institute. Available online at: http://shop.bsigroup.com/ProductDetail/?pid=000000000030331489

EFNARC (2002). Specification and Guidelines for Self-Compacting Concrete. European Federation of National Associations Representing for Concrete, Farnham, UK.

EFNARC (2006). Guidelines for viscosity modifying admixtures for concrete. European Federation of National Associations Representing for Concrete, Farnham, UK

FAA (2014). AC 150/5370-10G-Airport construction standards. Federal Aviation Administration, Part 6-Rigid Pavement, Item P-501 Portland Cement Concrete (PCC) Pavement. Available online at: https://www.faa.gov/airports/engineering/construction_standards/#content

Gambhir ML (2005). Concrete technology. McGraw-Hill Publishing Company, New Delhi, India.

Hawkins P, Tennis PD, and Detwiler RJ (2003). The use of limestone in Portland cement: A State-of-the-Art review. Portland Cement Association, Skokie, USA.

Hodhod H and Abdeen, MA (2010). Experimental comparative and numerical predictive studies on strength evaluation of cement types: Effect of specimen shape and type of sand. Engineering, 2(8): 559-572.

IPRF (2003). Best practices for airport Portland cement concrete pavement construction (rigid airport pavement). Innovative Pavement Research Foundation, Report IPRF-01-G-002-1.

IS (1988). Methods of physical tests for hydraulic cement, Part 5: Determination of initial and final setting times. Bureau of Indian Standard No. 4031-5. Available online at: https://law.resource.org/pub/in/bis/S03/is.4031.5.1988.pdf

Khayat KH and Assaad J (2002). Air-void stability in self-consolidating concrete. ACI Materials Journal, 99(4): 408-416.

Kurita M and Nomura T (1998). Highly-flowable steel fiber-reinforced concrete containing fly ash. Special Publication, 178: 159-176.

Mathur R, Misra AK, and Goel P (2014). Strength of concrete vs grades of cement. Central Road Research Institute, New Delhi, India.

MCAAT (2009). Flexural strength of concrete (The modulus of rupture test). Mohawk College of Applied Arts and Technology, Building and Construction Sciences Department. Available online at: http://docplayer.net/23216898-Flexural-strength-of-concrete-the-modulus-of-rupture-test.html

Naik TR (2008). Sustainability of concrete construction. Practice Periodical on Structural Design and Construction, 13(2): 98-103.

Ozawa K, Sakata N, and Okamura H (1995). Evaluation of self-compactibility of fresh concrete using the funnel test. Concrete Library of JSCE, 25: 59-75.

Ramadan KZ and Haddad RH (2017). Self-healing of overloaded self-compacting concrete of rigid pavement. European Journal of Environmental and Civil Engineering, 21(1): 63-77.

Sahana R (2013). Setting time compressive strength and microstructure of geopolymer paste. In the International Conference on Energy and Environment, International Journal of Innovative Research in Science, Engineering and Technology, 2(1): 311-316.

Sahu A and Mishra SP (2015). Analysis for strength in different types of cement available in Chhattisgarh. International Journal for Scientific Research & Development, 3(9): 709-714

Tande SN and Mohite PB (2007). Applications of self-compacting concrete. In the 32nd International Conference on Concrete and Structure. Organized by CI PREMIER PTE LTD, Singapore. Available online at: http://cipremier.com/100032055

Thomas J and Pasko Jr (1998).Concrete pavements - past, present, and future. Public Roads: Federal Highway Administration Research and Technology, 62(1): 7-15.

Wright PH (1996). Highway engineering. John Wiley and Sons, New Jersey, USA. Available online at: http://worldcat.org/isbn/0471826243