Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/

(RESEARCH ARTICLE)

Check for updates

Strength characterization of roller compacted concrete with GGBS as partial cement replacing material

Raksha J. Khare [1], Rajendra B. Magar [1] and Hemant S. Chore [2, *]

[1] *Department of Civil Engg. School of Engg. and Tech., Anjuman-I-Islam's Kalsekar Technical Campus, New Panvel (Maharashtra) India.*

[2] *Department of Civil Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar (Punjab) India.*

Global Journal of Engineering and Technology Advances, 2024, 18(03), 013–019

Publication history: Received on 12January 2024; revised on 29 February 2024; accepted on 02March 2024

Article DOI: https://doi.org/10.30574/gjeta.2024.18.3.0034

Abstract

The current study explores the optimization of roller compacted concrete (RCC) aiming at achieving zero-slump concrete. The RCC, composed of cementitious materials, sand, dense graded aggregates, and water, is primarily employed for pavements and various industrial applications. In this study, different RCC formulations were developed by replacing ordinary Portland cement (OPC) with ground granulated blast furnace slag (GGBS) at varying percentages (0%, 20%, 40%, and 50%). The investigation involved determining the optimal water content for each mix through comprehensive compaction tests at different replacement levels. The focus was on analysing the enhancement in the strength properties of RCC mixes with GGBS. The results indicate that RCC compositions incorporating GGBS exhibit lower early-age strength as compared to conventional OPC concrete. However, the strength of GGBS-modified mixes exhibits improvement over time, ultimately surpassing the compressive strength of normal OPC concrete. Notably, the test outcomes indicate that the strength properties of RCC mixes blended with GGBS increase significantly up to a 40% replacement level of OPC with GGBS.

Keywords: Roller compacted concrete; Ordinary Portland cement; Ground granulated blast furnace slag; Compressive strength; Flexural strength

1. Introduction

Roller compacted concrete (RCC) stands out as a zero-slump concrete renowned for its cost-effectiveness, robustness, and swift installation [1]. Similar to conventional concrete, RCC comprises constituents and follows a construction process similar to that of the asphalt pavement [2]. The fundamental constituents of RCC contain cementitious materials, dense-graded aggregates, and the water. Due to its limited water content, the RCC manifests as an ultra-dry mixture unsuitable for placement using conventional (slump) concrete methods. The compaction of the mix is carried out using vibratory rollers. The maximum size of coarse aggregates utilized in RCC varies depending on their application in dams or pavements with smaller-sized aggregates favouring for later applications. Its keen adoption over recent years owes much to its economic viability and ease of handling during transportation and placement, which avoids the need for formwork, reinforcing steel, and dowel bars in the RCC pavement construction, thereby reducing the overall construction cost. Moreover, the RCC limits transverse cracking through a denser particle structure, fostering superior aggregate interlock and interface adherence with the sub-base [3].

Remarkably, achieving comparable compressive strength to conventional concrete demands 20-28% less cementitious material in the RCC [4-5]. Besides conventional building materials, the incorporation of diverse mineral admixtures like micro-silica fume, fly ash, and ground granulated blast furnace slag (GGBS) not only reduces the cost of RCC but also

*Corresponding author: Hemant S. Chore.

augments the resultant mix properties [2, 6-8]. By-products, such as fly ash, bottom ash, andthe GGBS, pose significant disposal challenges due to their substantial volumes of production. However, redirecting these waste materials toward the construction industry presents an effective solution to these management issues. Beyond cost reduction, integrating industrial by-products into concrete formulation elevates the overall compressive strength while the inclusion of micro-silica concurrently reduces concrete permeability. The GGBS, a by-product from blast furnace iron production, mirrors the quantity of iron and slag produced [9]. It includes alumina, silica, magnesium oxide, and lime to those present in Portland cement but in different proportions

Various researchers have explored the utilisation of these industrial by-products in Roller Compacted Concrete (RCC) production. Cao *et al.* [6] examined the impact of high-volume fly ash (HFRCC) on RCC's compressive and flexural strength, noting superior long-term strength despite initial lower strength at early ages. Atis*et al.* [7] investigated fly ash in RCC, discovering enhanced compressive strength with 15% fly ash replacement, reaching levels akin to normal Portland cement at 30% replacement. Atis [10] delved further into RCC mixes with different low-lime Class F fly ashes, revealing varied strengths based on the type of fly ash used. Vahedifard*et al.* [5] assessed silica fume and pumice in low cement RCCP mixtures, observing increased compressive strength with 10% silica fume but reduced workability. Conversely, pumice improved workability but decreased compressive strength. Srivastava *et al.* [11] recommended 5% silica fume replacement, augmenting both workability and strength. Aghabaglou and Ramyar [8] investigated fly ash as a replacement for both cement and fine aggregates, observing reduced strength with increased cement replacement but higher strength when replacing fine aggregates. Hesami *et al.* [4] explored coal waste powder, coal waste ash, and limestone in RCC pavement, finding that a 5% replacement level matched control mix performance. Rao *et al.* [2] investigated fly ash and manufactured sand in RCC, noting improved performance with combined M-sand and fly ash. Various studies indicate RCC's potential to enhance workability, later-age strength, and durability despite the initial reduction in early-age strength [12-14].

Through literature study, it can be known that GGBS's efficacy in conventional concrete is well-studied, but its impact on RCC remains underexplored. Rao *et al.* [2] investigated GGBS in RCC, reporting optimal strength at 40% replacement. This study aims to achieve zero-slump concrete by replacing various percentages of cement with GGBS using a soil compaction approach, reducing voids and cement-water requirements for RCC pavement field applications. The research explored the long-term strength properties of RCC blends with varying GGBS contents up to 28 days post-casting.

2. Experimentation

2.1. Materials used

The materials used in this study included Ordinary Portland Cement (OPC), adhering to BIS: 8112 [15]. The cement was tested according to BIS: 4031 [16]. The river sand, with water absorption of 1.8 %, specific gravity of 2.70, and fineness modulus of 3.14, was used as the fine aggregates (FA). The aggregates of varying sizes, such as 6- 20 mm and having a specific gravity of 2.87, were used as coarse aggregates (CA). The potable and drinking water was used, and the ground granulated blast furnace slag (GGBS) was used in accordance with BIS: 12089 [17] as binding agents.

2.2. RCC mixture compositions

Along lines similar to that of conventional concrete mix design methodologies, various approaches exist for the mix designs of roller-compacted concrete (RCC). In this particular study, a soil compaction approach was employed to ascertain the mixture proportions for RCC. This method operates on the principle of achieving an optimal moisture content for a laboratory compaction effort, mirroring the compaction exerted by field rollers. As outlined in ACI 211.3R-02 [18], the process begins by establishing the proportion of aggregate to be utilized. Subsequently, the determination of cementitious material content and water is executed through the application of the optimum moisture content method, defined in ASTM D 1557 [19].

2.3. Proportioning of aggregates

The composition of aggregates in the RCC mixture was accurately chosen to craft a dense-graded combined aggregates curve in accordance with the guidelines outlined in ACI 211.3R-02 [18]. The diverse combinations of fine aggregates and 10 mm and 20 mm coarse aggregates were experimented in order to derive the optimal combined aggregate curve. After rigorous trials, the composition featuring 55% fine aggregates, 30% of 10 mm size coarse aggregate; and 15% of 20 mm size coarse aggregate yielded a dense-graded aggregate curve that conformed to the specified limits defined in ACI 211.3R [18].

2.4. Sample preparation

The RCC mixture preparation involved a rotating mixer with a standardized mixing time of 5 minutes. Achieving comprehensive compaction relied on a vibrating table set at a frequency of 60 Hz, complying with ASTM C 1170 [20] specifications. Following a 24-hour casting period, all specimens were de-molded and placed within a curing tank set at a consistent temperature of 25 ± 2°C and 100% relative humidity. Table 1 gives the particulars of the RCC mix proportions.

Table 1 RCC mix proportion

Mix Notation	Cementitious materials (kg/m³)		Water (kg/m³)	Aggregates		w/c
	Cement (kg)	GGBS (kg)		6-12.5 mm	12.5-20 mm	
R0	440	0	150	517.82	360.98	0.34
R-G20	352	88	157.8	505.30	347.40	0.36
R-G40	264	176	159.10	503.61	333.91	0.38
R-G50	220	220	163.40	500.83	323.28	0.4

The test specimens of size (a) 150 × 150 ×150 mm were cast for evaluating the compressive strength, 150 mm diameter samples were cast to evaluate split tensile strength and the beams of 150 × 150 × 700 mm size were cast to evaluate the flexural strength. The compressive strength assessments were conducted after 7 and 28 of curing in accordance with BIS: 516 [21] guidelines. Additionally, split tensile strength and flexural strength tests were executed at 7, 14, and 28 days of curing, aligning with BIS: 516 [21] standards.

3. Results and discussion

3.1. Compressive strength

The compressive strength of the RCC mixes tested at the intervals of 7 and 28 days are graphically indicated in Fig.1. The results represent the average of the compressive strength values of three samples obtained for each mix.

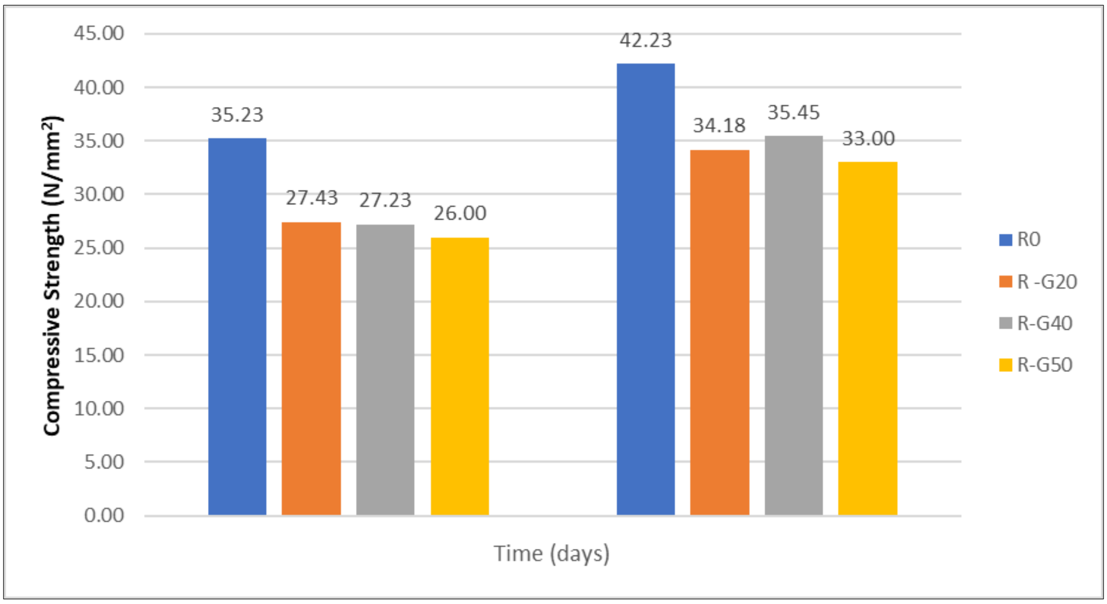

Figure 1 Variation of compressive strength in various mixes for 7 and 28 days curing

At 7 seven days curing, the compressive strength in the control mix is found to be quite higher as compared to that of the RCC mixes containing GGBS in various percentages considered in the study. Out of the three mixes with 20%, 40%

and 50% GGBS, the strength of the mix containing 20% and 40 GGBS is almost equal; the mix containing 20% GGBS shows a slightly higher value. The compressive strength of the mix having 50% GGBS is slightly less (by 1.4 MPa). When the percentage variation in the compressive strength with respect to all the RCC mixes with 20%, 40% and 50% GGBS in the context of the strength in the control mix is compared, the decrease in strength is found in all the mixes by 22.14%, 22.7% and 26.2%, respectively. Further, when the variation in strength is considered w.r.t. that of mix R-G20, the strength is found to be less by 0.73% in the mix R-G40 and 5.2% in the mix R-G50.

At a higher curing period of 28 days, the compressive strength in the control mix is found to be significantly higher when compared with the strength obtained in all three RCC mix compositions with GGBS contents. All three mixes are found to exhibit a strength more than 30 MPa with the second mix (with 40% GGBS) showing the highest value and the one with 50% GGBS) showing the least value out of the three RCC mixes blended with GGBS as the cement replacing material. When the percentage variation in the compressive strength with respect to all the RCC mixes with 20%, 40% and 50% GGBS in the context of the strength in the control mix is compared, the decrease in strength is found in all the mixes by 19 %, 16 % and 22%, respectively. Further, when the variation in strength is considered w.r.t. that of mixR-G20, the strength is found to increase by 3.72% in the mix R-G40 and decrease by 3.45% in the mix R-G50.

The strength of the RCC mix with 40% GGBS shows a higher strength as compared to other RCC mixes with GGBS corresponding to 28 days curing. This demonstrates that 40% GGBS replacement can be considered as the optimal. This further aligns with findings noted in studies by Liu *et al.* [13] and Li and Zhao [22]. The early age compressive strength in respect of all three mixes is found to be greater than 20 MPa, which indicates the suitability of all the mixes in the construction of rigid pavement based on the criterion of early age strength. However, as per Indian Standards (IRC:44 and IRC-SP:62) [23-24],the minimum compressive strength of the concrete corresponding to 28 days' curing should be 40 MPa for application in the construction of the pavement of urban roads and 30 MPa for pavement or rural roads. Based on the aforementioned criteria, all the mixes considered in the present study are found suitable for application in the construction of roads in rural areas where the traffic is less. Moreover, at the 28-day mark, all the RCC compositions exhibit compressive strengths surpassing the specified minimum value of 27.6 MPa, crucial for the utilisation of RCC as a surface course, as described in ACI 325.10R [1]

3.2. Split tensile strength

Figure 2 exhibits the split tensile strength of various RCC mixtures. At an early curing age of 7 days, all the mixes with GGBS, i.e., R-G20, R-G40, and R-G50, show an increase in strength when compared with the increase in GGBS contents. However, when the strength is compared with what is seen in the case of the control mix (R0), the strength is found to be less in all three mixes. The percentage decrease in strength is found to be 34, 30 and 21%, respectively, when compared with the control (R0) mix. Further, when the variation in strength is considered w.r.t. that of mix R-G20, the splitting tensile strength is found to increase by 5.5% in the mix R-G40 and 20% in the mix R-G50.

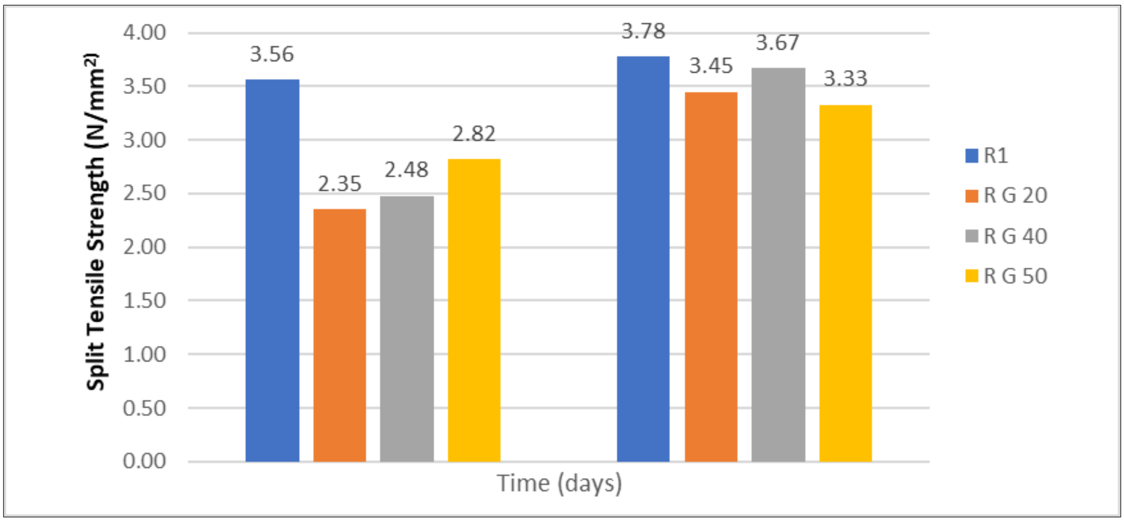

Figure 2 Variation of split tensile strength in various mixes for 7 and 28 days curing

At the higher curing period considered in the study, i.e., of 28 days curing, the strength of the mixes R-G20, R-G40, and R-G50 increases with increase in GGBS contents up to 40% and thereafter decreases at higher GGBS contents of 50%. When compared with the splitting tensile strength observed in case of the controlled mix (R0) with only cement, decrease in the strength in mix R-G20 is found to be 8.7%; in mix R-G40, 3%; and in mix R-G50, around 12%. Further, when the variation in strength is considered w.r.t. that of mix R-G20, the strength is found to increase by 6.4% in the mix R-G40 and reduce by 3.5 % in the mix R-G50. When the split tensile strength in the mixes with GGBS, the mix R-G 40 is found to show significant increase in the strength.

In accordance with ACI 325.10R-95 [1] criteria, the splitting tensile strength for RCC pavement for 28 days' curing should range between 2.8 and 4.1 MPa. Importantly, all RCC mixtures considered in this study fulfils this requirement.

3.3. Flexural strength

The flexural strength for all the RCC mixes and that for the control mixes in respect of 7 and 28 days curing is indicated in Fig. 3.

At 7 days' curing, the flexural strength in all the RCC mixes is found less when compared with the control mix. Further, when the trend of strength variation is compared in all three mixes with GGBS contents vis-à-vis, it is seen that the strength reduces with increase in GGBS contents. When the decrease in the strength is compared in the context of the strength in respect of control mix, the decrease of 31.4%, 38.6% and 44.76% is observed in the mixes R-G20, R-G40 and R-G50. Further, when the variation in strength is considered w.r.t. that of mix R-G20, the strength is found decrease by 10.4% in the mix R-G40 and 19.4 % in the mix R-G50.

At higher curing period of 28 days' curing, the flexural strength of the control mix is found to be 5.2 MPa and the strength in respect of the mix compositions with GGBS contents is found to be above 3.5 MPa. The strength of the mix with 40% GGBS is comparatively higher when compared with the strength of the mix with 20% GGBS and that of the mix with 50% GGBS is on lower side. This indicates that the 40% replacement of cement with GGBS is found to yield optimum strength. Further, when compared with the splitting tensile strength observed in case of the controlled mix (R0) with only cement, decrease in the strength in mix R-G20 is found to be 16.9%; in mix R-G40, 12%; and in mix R-G50, around 33%. Moreover, when the variation in strength is considered w.r.t. that of mix R-G20, the strength is found to increase by 6% in the mix R-G40 and decrease by 19.4 % in the mix R-G50.

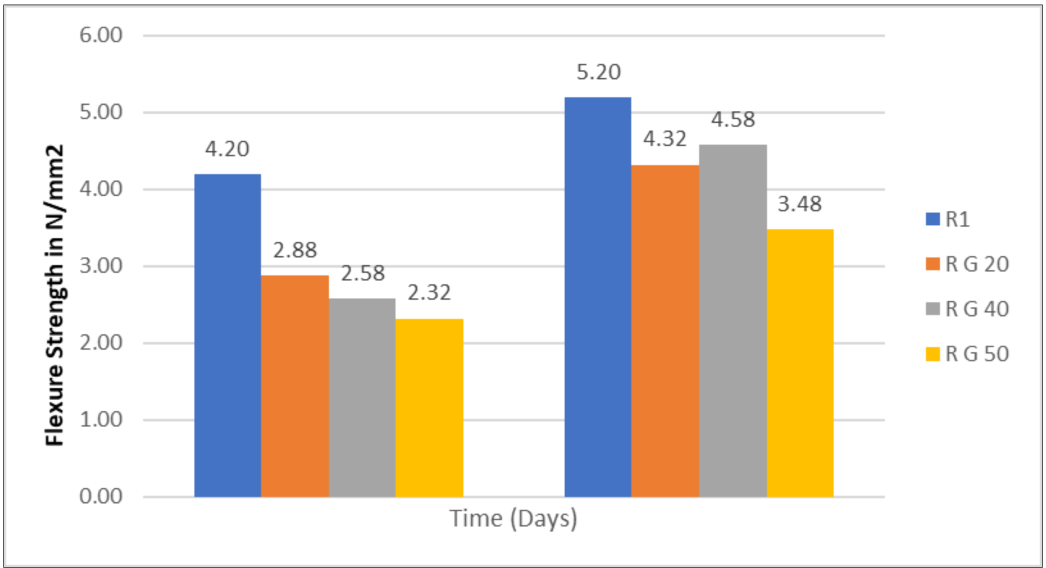

Figure 3 Variation of split tensile strength in various mixes for 7 and 28 days curing

As per IRC: 44 [23] and IRC-SP:62 [24], the minimum flexural strength of the concrete mixes corresponding to 28 days curing should be 4.5 MPa and 3.8 MPa for the application in the construction of pavements for urban roads and rural roads, respectively. When the values of the flexural strengths of three mixes considered in the study are seen, the mix R-G40 having the value of flexural strength of 4.58 is suitable for construction of roads in the urban area and the remaining two mixes, i.e., R-G20 and R-G50, are suitable for application in the construction of pavements in the rural area.

4. Summary and conclusions

The mechanical properties of the roller compacted concrete using granulated blast furnace slag (GGBS) are evaluated for possible application in the pavement in the present study. Three contents of GGBS (20%, 40% and 50%) are considered as the substitution to OPC. The mechanical properties are evaluated in terms of compressive, split tensile and flexural strengths. Based on the results of all the strength parameters, following broad conclusions can be arrived upon.

- All the three mixes are suitable for the construction of pavements irrespective of their application in the urban or rural area based on the early age compressive strength criterion.
- Based on 28 days' compressive strength criteria as per Indian Standards, all the three mixes are suitable for construction of concrete pavement in the rural area which caters to the low traffic.
- Based on 28 days' flexural strength, the mix R-G 20 and R-G50 is suitable for use in the pavements meant for rural area and the one (R-G40) meant for urban area.
- Considering the compressive and flexural strengths together, all the three mixes are suitable for use in the rural roads only.
- The mix R-G40, having 40% replacement of cement with GGBS, is found to yield the most optimised mix when seen in the context of compressive, split tensile and flexural strength values.

Compliance with ethical standards

Acknowledgement

The authors would like M/s Concretech India for providing necessary facilities for the experimentation in their plant.

Disclosure of conflict of interest

All the authors would like to declare that there is no conflict of interest relevant to this article

References

[1] ACI 325.10R -95 (2001). Report on roller-compacted concrete pavements. American Concrete Institute.

[2] Rao SK, Sravana P and Rao TC. (2016). Investigating the effect of M-sand on abrasion resistance of fly ash roller compacted concrete. Construction and Building Materials,118,352–363.

[3] Zollinger D. (2016). Roller compacted concrete pavement. U.S. Department of Transportation, FHWA–HIF–16–003.

[4] Hesami S, Modarres A, Soltaninejad M and Madani H. (2016). Mechanical properties of roller compacted concrete pavement containing coal waste and limestone powder as partial replacement of cement—Construction and Building Materials,111,625–636.

[5] Vahedifard F, Nili M. and Meehan CL. (2010). Assessing the effect of supplementary cementitious materials on the performance of low-cement roller compacted concrete pavement. Construction and Building Materials, 24,2528–2535.

[6] Cao C, Sun W. and Qin H. (2000). The analysis on strength and fly ash effect of roller-compacted concrete with high volume fly ash. Cement and Concrete Research,30,71–75.

[7] Atis, CD, Sevim UK, Ozcan F, Bilim C, Karahan O, Tanrikulu AH and Eksi A. (2004). Strength properties of roller compacted concrete containing a non-standard high calcium fly ash. Materials Letters,58,1446–1450.

[8] Aghabaglou AM and Ramyar K. (2013). Mechanical properties of high-volume fly ash roller compacted concrete designed by maximum density method. Construction and Building Materials 38,356–364.

[9] Oner A and Akyuz S. (2007). An experimental study on optimum usage of GGBS for the compressive strength of concrete. Cement and Concrete Composites,29,505–514.

[10] Atis CD. (2005). Strength properties of high-volume fly ash roller compacted and workable concrete, and influence of curing condition. Cement and Concrete research, 35,1112–1121.

[11] Srivastava V, Kumar R, Agarwal VC. and Mehta PK. (2014). Effect of silica fume on workability and compressive strength of OPC concrete. Journal of Environmental Nanotechnology, 3(2),32–35.

[12] Swamy RN and Bouikni A. (1990). Engineering properties of slag concrete as influenced by mix proportioning and curing. ACI Material Journal,87,210–220.

[13] Liu S, Wang Z. and Li X. (2014). Long-term properties of concrete containing ground granulated blast furnace slag and steel slag. Magazine of Concrete Research 66(21), 1095–1103.

[14] Chidiac SE and Panesar DK. (2008). Evolution of mechanical properties of concrete containing ground granulated blast furnace slag and effects on the scaling resistance test at 28 days. Cement and Concrete Composites,30(1), 63–71.

[15] BIS 8112- 1989, Reconfirmed (2005). Specification for 43 Grade Ordinary Portland Cement. Bureau of Indian Standards, New Delhi.

[16] IS:4031(1988) Indian Standard Methods of Physical Test for Hydraulic Cement

[17] BIS 12089 (1987). Reconfirmed (2004). Specification for Granulated Slag for the manufacture of Portland Slag cement. Bureau of Indian Standards, New Delhi.

[18] ACI 211.3R-02 (2002). Guide for selecting proportions for No- slump concrete. American Concrete Institute.

[19] ASTM D1557 (2009). Standard test methods for Laboratory compaction characteristics of soil using modified efforts. American Society of Testing and Materials, Philadelphia.

[20] ASTM C 1170/C1170M (2008). Standard test method for determining consistency and density of roller compacted concrete using a vibrating table. American Society of Testing and Materials, Philadelphia.

[21] BIS 516 – 1959, Reconfirmed (2004). Indian Standard Methods of Tests for Strength of Concrete. Bureau of Indian Standards, New Delhi.

[22] Li G and Zhao X. (2003). Properties of concrete incorporating fly ash and ground granulated blast-furnace slag. Cement and Concrete Composites,25,293–299.

[23] IRC 44 (2018). Guidelines for Cement Concrete Mix Design for Pavements.

[24] IRC SP62-(2014). Guidelines for design and construction of cement concrete pavements for low volume roads. Indian Roads Congress, New Delhi