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Research Paper

Packing Density Approach for Sustainable Development of Concrete

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ABSTRACT

This paper deals with the details of optimized mix design for normal strength concrete using particle packing density method. Also the concrete mixes were designed as per BIS: 10262-2009. Different water-cement ratios were used and kept same in both design methods. An attempt has been made to obtain sustainable and cost effective concrete product by use of particle packing density method. The parameters such as workability, compressive strength, cost analysis and carbon di oxide emission were discussed. The results of the study showed that, the compressive strength of the concrete produced by packing density method are closer to that of design compressive strength of BIS code method. By adopting the packing density method for design of concrete mixes, resulted in 11% cost saving with 12% reduction in carbon di oxide emission.

1 Introduction

Concrete is one of the most extensively used construction material in the entire world. Environmental issues and sustainability will play an important role in the development of this concrete industry in this century. A sustainable concrete structure is one, which has environmental influence within certain limits, which on construction, utilization and demolition by the current generation would not affect the quality of life of the future generation. Such concrete structures also reduce negative impact on air quality and minimize solid waste generation. One way of achieving these goals is by minimizing the extent of utilization of cement by adopting some alternative design methods of concrete.

Concrete is a multiphase material consisting of coarse aggregate, fine aggregate, binding material and water. Thus, the properties of concrete depends upon the characteristics of the aggregates, performance of cement paste and interfacial transition zone [1-2]. Approximately 75% of the concrete volume is occupied by the aggregates in which around 45% are coarse aggregate, it is assumed that the aggregate properties greatly affect the durability and the structural performance of concrete material [3]. In concrete, cement is very expensive item than aggregates and is responsible for huge amount of

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carbon di oxide generation. So maximizing the packing density of aggregate particles will reduce the cost of concrete production and it support to sustainable development.

The mix design is basic essential tool for concrete technology and basic principal of the mix design is to obtain required properties of material at minimum cost. For sustainable concrete production the basic tool is concrete mix design. In the recent years huge evolution made in the concrete technology and new types of concretes such as high performance concrete, self-compacting concrete [4] and recycled aggregate concrete, etc. [5] are produced. These new revolutionary technology requisites a new development for optimized mix design methods of concrete. The performance of concrete is governed by two states namely fresh and hardened state. In the fresh state if concrete not workable then it cannot be placed and competed. In hardened state the compressive strength is the main factor which governs its property and it seems to be sign for good concrete.

There are various existing methods developed by the various countries and these methods are used for design of concrete mixes such as BIS code method, British code method, ACI code method, etc. In general practice the concrete mixes are designed by using given standards. The aggregates and cement are tested in labs and with the help of data available in the codes for the design of mixes. The concept of particle packing density was first utilized in 1892 by Feet, to optimize the aggregate gradation. The main objective of the particle packing density is to obtain the dense packing of aggregate particle and to minimize the cement requirement [6]. While designing the concrete mix by packing density approach more emphasis is given on the combination of aggregates i.e. coarse and fine aggregates. The coarse aggregate and fine aggregate are mixed in different proportions to arrive at maximum packing density and minimum void content. The cement paste is added in the selected mixture of aggregates to achieve desired workability and strength. Generally it is considered that, the performance of concrete can be improved by minimizing the void content and their interconnectivity [7]. To obtain this, a particle packing density method is an important tool. The increase in packing density and reduced voids content in aggregate mixture results in reduced amount of binder required to give the desired strength of concrete mix [8].

In a study by Raj et al. [9], the compressive strength obtained by packing density approach are comparable to that of BIS code method for a given water-cement ratio. They had developed co-relation curves between compressive strength and waster-cement ratio and compressive strength vs cement paste content. Theses curves were used to decide the water-cement ratio and paste content for specified grade of concrete in packing density method. Fennis et al. [10], in their study reported that concrete mixes can be designed by using particle packing method and it is possible to reduce the cement content up to 50% and the CO_2 emission can be reduced by 25%. Another study carried out by Jeenu et al.[11], the packing density was measured by using seven types of fractions of aggregate with four different series of mixes. A generalized empirical equation for obtaining an effective particle size distribution of aggregates for optimal performance of concrete was proposed. By using this equation the gradation curve was plotted, the packing density and compressive strength was found to be maximum as compared to the standard gradation curves. Kwan et al. [12] reported that, the packing density of concrete mix with pulverized fuel ash, and condensed silica fume increases with use of third generation poly-carboxylate based super plasticizers. He also reported that, the use of cement in the range of 15% to 20% by volume in concrete mixes gives minimum void content.

In the present study the application of particle packing density for design of normal strength concrete is explained. Also the concrete mix is designed by using BIS method with different water-cement ratios and these ratios were also used for design of concrete mixes by packing density method. The comparison and benefits of use of packing density methods for design of concrete mixes is explained.

2 Experimental Study

2.1 Characterization of Materials

Portland Pozzolana cement used in this study fulfills the requirement of BIS: 1489-part 1 1991 [13]. The initial and final setting time, consistency and compressive strength of cement are shown in Table 1.The sand used in this study conforms to grading zone II of BIS: 383-1960 [14]. The proportion of sand are presented in Table 2. The coarse aggregate used in this study confirms to BIS: 383-1960 [14]. The Specific gravity and water absorption of coarse aggregate are presented in Table 2. The nominal maximum size of coarse aggregate used was 20 mm. To achieve the desired slump of 75 mm, a third generation poly-carboxylate based super-plasticizer Rheobuild 522 ND conforming to BIS: 9103-1999 [15] was used.

Table 1 - Physical Properties of Cement

Initial Setting Time	47 minute
Final setting time	483 minute
Compressive strength	
3 days	20MPa
7 days	24MPa
28 days	39MPa
consistency	27%
Specific gravity	3.11

Table 2 - Physical Properties of Aggregates

Aggregate Type	Specific gravity	Water Absorption (%) by weight	Grading Zone
Coarse aggregate	2.61	0.54	As per Table 2 of BIS 383
Fine Aggregate	2.66	2.0	Zone II As per Table 4 of BIS 383

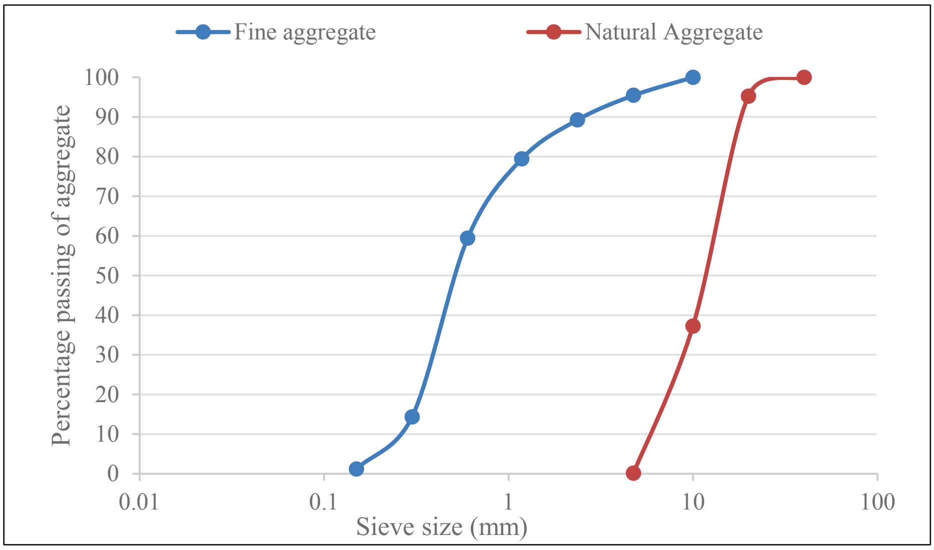

Figure 1- Particle size distribution of coarse aggregate

2.2 Concrete Mix Proportioning

The mixture proportions of concrete designed by BIS: 10262-2009 [16] are given in Table 3 and the mixture proportion of concrete designed by packing density approach are given in Table 4. For the design of concrete mix by packing density approach various formulations of aggregate fractions were prepared. Firstly two size fractions of coarse aggregate 20 mm and 10 mm were mixed in a definite proportion by weight, such as 90:10, 80:20, 70:30 and 60:40, etc., and the bulk density of each mixture was determined. However, a stage was reached when the bulk density of the coarse aggregate mixture, instead of increasing, decreases again. The mixture giving highest bulk density was mixed with fine aggregate in the ratio of 90: 10, 80: 20, 70: 30, 60: 40, 50: 50, etc. By increasing the finer content, the bulk density increases up to a peak value after which it again reduces. Thus, the proportion obtained for maximum bulk density was fixed for total aggregates, i.e., coarse aggregates 20 mm: coarse aggregates 10 mm: fine aggregates was 36: 24: 40 by weight. The bulk density, packing density and voids contents are plotted against the weight fraction of all in aggregate are presented in the Figure 2, Figure 3 and Figure 4, respectively.

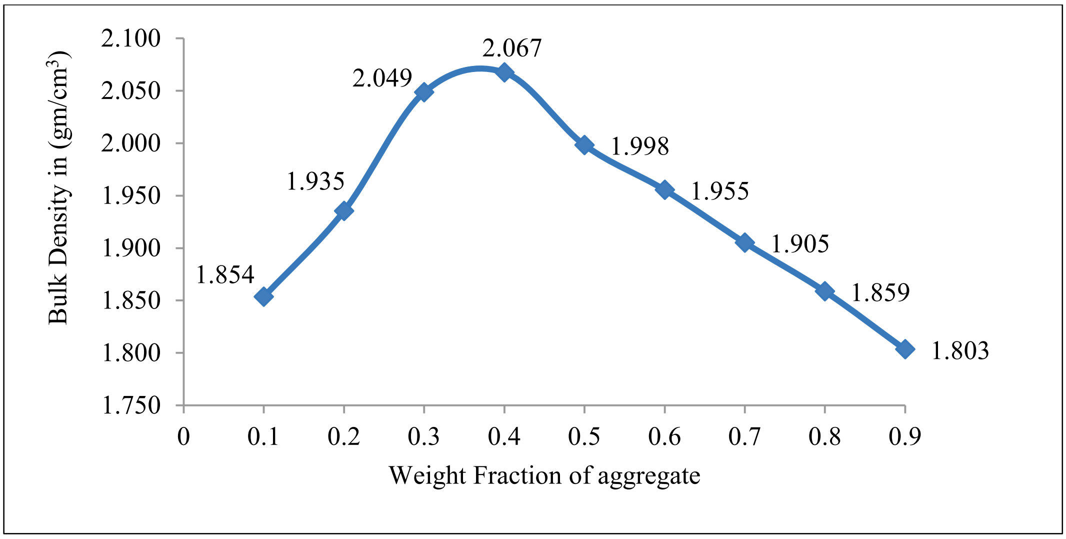

Figure 2- Bulk Density of all in aggregate

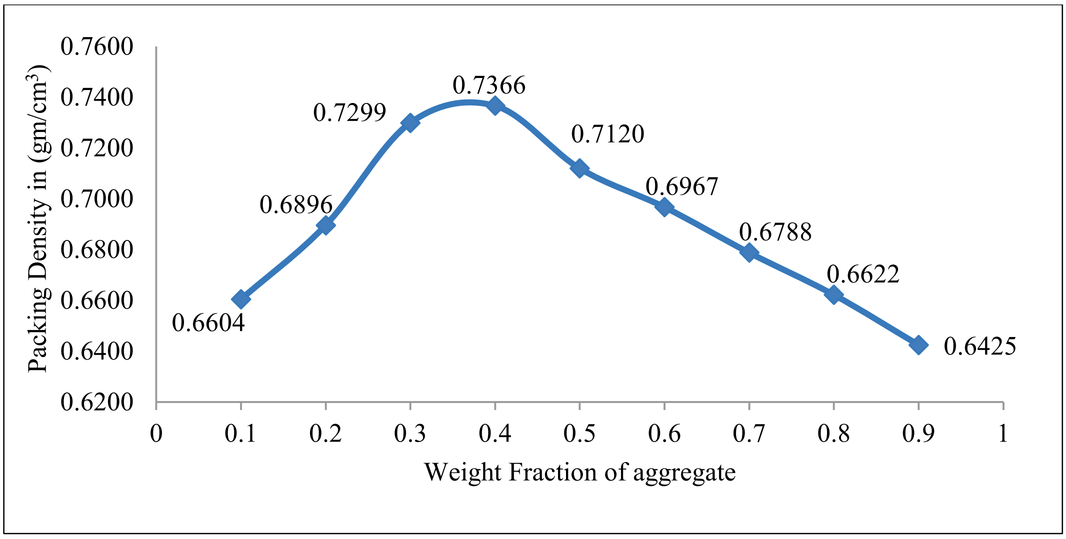

Figure 3- Packing Density of all in aggregate

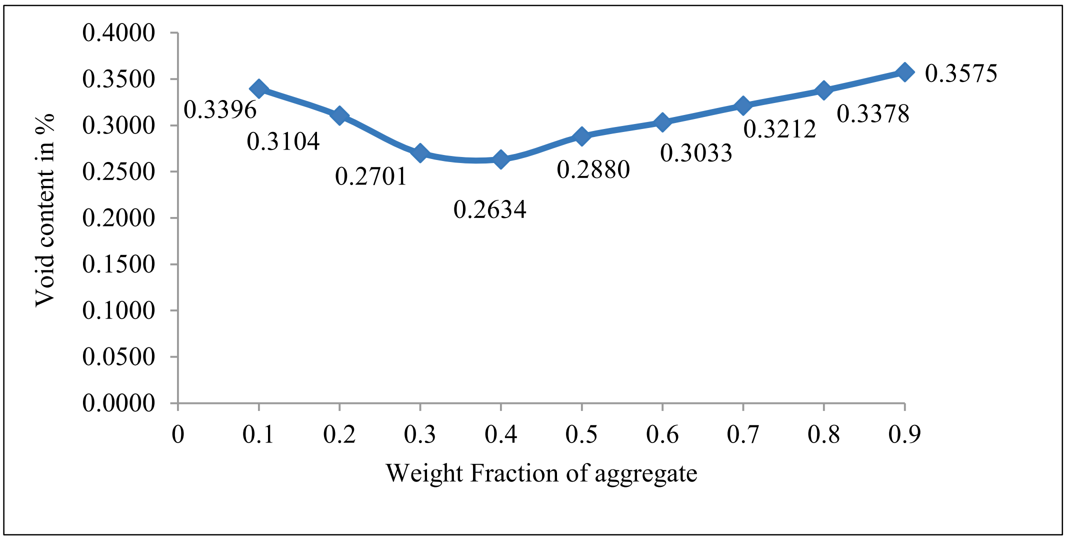

Figure 4- Void content of all in aggregate

After getting all the values of bulk density, packing density and void contents the mix proportion of concrete were calculated. The concrete mix was prepared by taking cement paste content 0%, 5%, 10%, 15% and 20% in excess of void content in the aggregate mix. The mix proportions by both approaches are given in Table 3 and Table 4. The concrete mixes were prepared by using a different water-cement ratios. Before the addition of water, the dry concrete mixes were blended for 5 minutes to achieve a thorough mix in a 160 lit capacity mixer.

Table 3 - Mix Proportion of Concrete by BIS Code Method (Quantity in Kg/m^3)

w/c ratio	water	cement	sand	Coarse Aggregate
0.55	192	348	724	1184
0.50	192	383	692	1184
0.45	192	426	663	1180
0.40	160	380	707	1258
0.35	152	435	660	1282

Table 4 - Mix Proportion of Concrete by Packing Density Method (Quantity in Kg/m^3)

w/c ratio	Paste content in excess of voids (%)	water	cement	sand	Coarse Aggregate
0.55	10	169	308	800	1205
0.50	10	163	327	800	1205
0.45	10	157	348	800	1205
0.40	10	149	372	800	1205
0.35	10	140	400	800	1205

From the Table 4 it was observed that, the fine and coarse aggregate content in packing density method was considerably more than that of BIS code method.

2.3 Sample preparation and test methods

The ingredients of concrete were mixed in a mixer and cubes of size 150 mm × 150 mm ×150 mm were cast for determining the compressive strength of test specimens. All the specimens were de-moulded at the age of 24 ± 1 h and thereafter were cured in water tank at room temperature up to the specified age of test.The slump cone test on freshly prepared concrete mix was carried out as per BIS:1199-1959 [17] for measuring workability of concrete. Compressive strength of concrete specimens was determined at 7 days and 28 days curing age as per BIS: 516-1959 [18].

3 Results and Discussion

3.1 Workability

The variation in workability of concrete mixes designed by different methods with different water-cement ratios are presented in Table5.

Table 5 - Variation in Workability of Concrete Mixes

W/C	BIS code method		Packing Density Method	
	Dose of super-plasticizer by weight of cement (%)	slump (mm)	Dose of super-plasticizer by weight of cement (%)	slump (mm)
0.55	0.25	80	0.50	100
0.50	0.25	90	0.65	90
0.45	0.50	100	0.90	90
0.40	0.70	90	1.0	90
0.35	0.25	80	2.3	100

It can be seen from the above table that, all the concrete mixes achieved their target slump of 75-100 mm. While achieving the target slump the dose of super-plasticizer is increased. In case of packing density method at all water-cement ratio the dose of super-plasticizer required is more than that of BIS code method. This increase is caused by the increased sand content in concrete mixes designed by packing density method as seen in Table 6. On an average sand content increased by 14% in packing density method as compared to that of BIS code method. The increased sand content absorbs more water from the mix resulted in stiff mix. Hence higher dose of super-plasticizers is required to achieve the desire workability.

3.2 Compressive Strength

The variation in compressive strength of concrete mixes designed by BIS code method at different water-cement radios are presented in Figure 5. From the Figure it can be seen that, all the concrete mixes designed by BIS code method achieved target mean strength after 28 days curing at all water-cement ratios.

The results of compressive strength test of concrete mixes designed by packing density method are shown in Table 6. It was observed that, for all water-cement ratios the concrete mixes achieved the strength nearly equal to that of BIS code methods with the reduced cement content. On an average an approximately 14% saving in cement content was archived in all concrete mixes as compared to that of BIS code method. The compressive strength of the concrete designed by packing density method was marginally higher than that of BIS code method at 0.55, 0.50 and 0.45 water-cement ratios. This marginal increase was due to enhanced packing of particles within the concrete mix. The strengths obtained at all water-cement ratio of the concrete mixes designed by packing density approach was nearly close to that of designed compressive strength of BIS code methods. This was due to dense packing of particles with in the concrete. The dense packing was achieved due to increased fine and coarse aggregate content. The fine and coarse aggregate content was increased by approximately 14% and 4%. This increased aggregate content increase packing density and reduces void content which helps in making aggregate-cement paste bond strong [19].

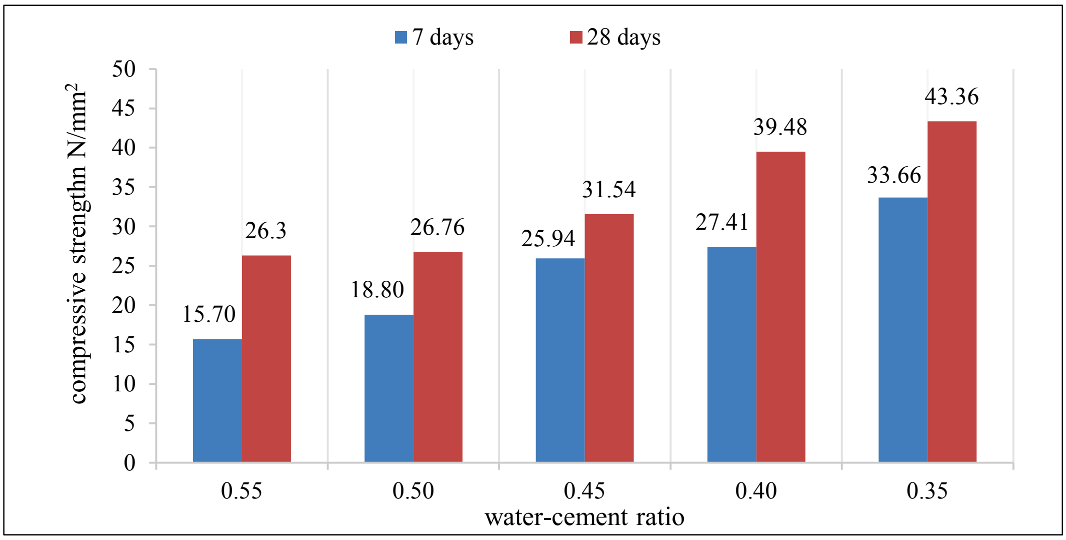

Figure 5- Variation in compressive strength of concrete mixes designed by BIS code method

Table 6 - Saving in Cement Content

W/C ratio	Cement Content in Kg/m3			
	BIS code method	Packing Density method	Saving in cement by PDM(kg)	% saving in cement
0.55	348	308	40	11.49
0.5	383	327	56	14.62
0.45	425	348	77	18.12
0.40	400	372	28	7.00
0.35	435	400	35	8.05

3.3 Saving in cement content and cost comparison

Table 6 shows the saving in cement content in concrete mixes designed by packing method. From this table it was observed that, the concrete mixes designed by packing density method are economical because of saving in cement content. The maximum saving of 18% was achieved at 0.45 water-cement ratio. The concrete mixes designed by packing density method showed an average 12% reduction in cement content as compared to that of BIS code method. It depicts that the concrete mixes designed by packing density method are economical.

Table 7 shows the cost analysis of the concrete mixes. From this analysis it was observed that, the concrete mixes designed by packing density method show saving in material cost of concrete. The average cost of material for production of concrete can be reduced by 11% by adopting the packing density method for design of concrete mixes. Hence it clearly indicates that, the concrete mixes designed by packing density method are cost effective and economical.

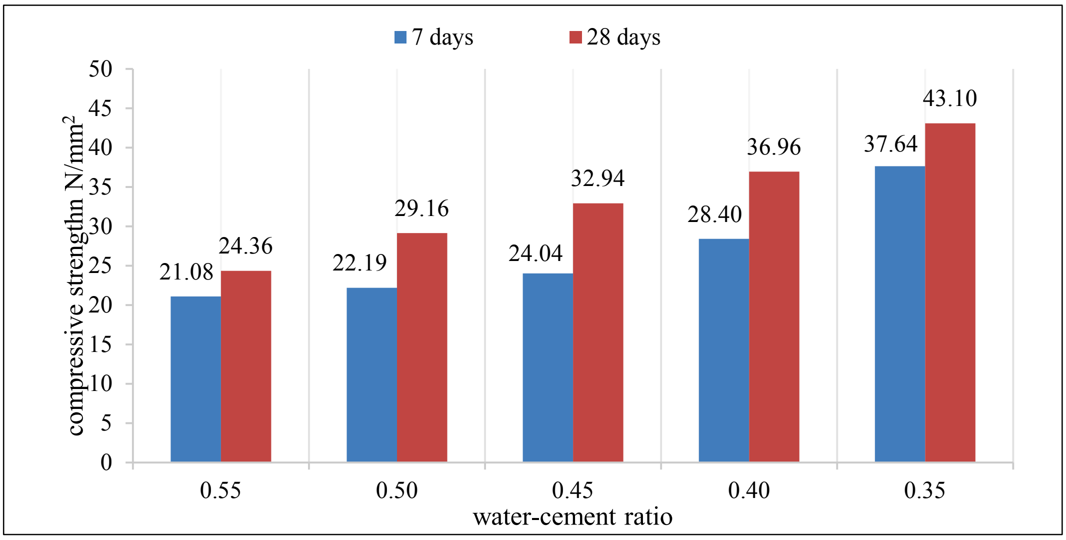

Figure 6- Variation in compressive strength of concrete mixes designed by packing density method

Table 7 - Cost of Material for Production of 1m^3 of Concrete

	Cost of material in Rs. for 1m^3 of concrete			
w/c ratio	**BIS code method**	**Packing density method**	**Saving in cost**	**Percentage saving**
0.55	2817	2640	177	6
0.50	2995	2746	249	8
0.45	3217	2864	353	11
0.42	3295	2998	297	9
0.35	3311	3155	156	5

3.4 CO_2 production

The cement manufacturing industry is major contributor for CO_2 emission in the world. The contribution of cement industry in greenhouse gas emission is around 3.95 billion tons annually and that is 7% of the total greenhouse gas emissions on the earth's surface [20]. The global annual production of the concrete in the year 2014 was 4.2 billion tons and it is expected that this figure may increase by 2.9 % by 2018 [21]. In India around 275 MT of cement was produced during the year 2014 which account for generation of equal amount of CO_2 [22 - 23]. For the production of 1Ton of cement around 0.94 Ton of CO_2 is released [21]. The CO_2 emission factor for road transport, i.e. truck or lorries is considered as 512.2 g/km [24].

Table 8 - Reduction in Carbon di Oxide Emission

Cement Content in Kg/m3			CO_2 emission (Kg/m^3)		Percentage reduction in CO_2 emission by packing density method
W/C ratio	BIS code method	Packing Density method	BIS code method	Packing Density method	
0.55	348	308	327	289	11
0.5	383	327	360	307	15
0.45	425	348	400	327	18
0.40	400	372	376	350	7
0.35	435	400	409	376	8

Form the above Table 6 it can be observed that, the cement content required for the design of concrete mixes by using packing density method reduced by 12%. On the other hand from Table 8 it can be observed that, the reduced usage of cement content for concrete mix resulted in average 12% reduction in carbon di oxide emission as compared to that of BIS code method. Adopting packing density approach for design of concrete mixes would reduce the annual global cement production from 4.2 billion tons by 0.51 billion tons and CO_2 release from 3.95 billion tons to 3.47 billion tons. The concrete produced using packing density approach is not only cost effective and sustainable product mitigating environmental pollution to a large extent.

4 Conclusions

In this paper the particle packing density method was applied for design of concrete mixes with different water-cement ratio, also the concrete mixes were designed as per BIS code method at same water-cement ratio. The fresh and hardened properties of concrete was carried out. From the above study following conclusions were drawn,

- The fine and coarse aggregate content required are more in packing density method as compared to that of BIS code method at all water-cement ratios.
- Designing the concrete mixes by packing density method, the required quantity of cement content was reduced by 12% as compared to that of BIS code method.
- All the concrete mixes achieved desired workability but the required dose of super-plasticizer was more in packing density method as compared to that of BIS code method due to increased fine aggregate content.
- The compressive strength of all the concrete mixes designed by packing density method are nearly close to that of BIs code method with reduced cement content.
- The cost analysis showed that, concrete mixes produced using packing density method are economical than that of BIS code method at all water-cement ratios.
- The reduced usage of cement content resulted in 12% lesser emission of carbon di oxide in environment which is one of the most important benefit resulting from the above study.

From the above study it can be concluded that, the use of particle packing density method for design of concrete mixes gives clear indication to follow the packing density method for design of concrete mixes. The product become sustainable with saving in 11% overall cost of concrete designed by packing density approach with 12% reduction in CO_2 emission.

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