Gokaraju Rangaraju Institute of Engineering and Technology

(Autonomous)

Department of Civil Engineering

YEAR 2018

Year	Number of Journal Publications			Number of Conference Proceedings	
	SCI	SCOPUS	UGC	SCOPUS	UGC
2018	0	6	0	0	0

JOURNAL PUBLICATIONS:

SCI JOURNALS:

NIL

SCOPUS JOURNALS:

1. S Shrihari, M V Seshagiri Rao, **V Srinivasa Reddy** and Venkat Sai (2018), “Mix proportioning of M80 grade Self-Compacting Concrete based on Nan Su Mix design method principles”, International Journal of Engineering & Technology, 7 (3.35) (2018) 52-54

2. **V Srinivasa Reddy**, R Nirmala (2018), “ Development of quaternary blended high performance concrete made with high reactivity metakaolin”, International Journal of Engineering & Technology, 7 (2.1) (2018) 79-83

3. C. Chandana Priya, M. V. Seshagiri Rao and **V. Srinivasa Reddy** (2018), “Studies On Durability Properties Of High Strength Self-Compacting Concrete –A Review”, International Journal of Civil Engineering & Technology (IJCIET) - SCOPUS indexed, Volume 9, Issue 11, (November 2018), pp. 2218–2225, Article ID: IJCIET_09_11_219, ISSN Print: 0976 – 6308, ISSN Online: 0976 – 6316

4. M V Jagannadha Kumar, B Dean Kumar, K Jagannadha Rao and **V Srinivasa Reddy** (2018), "Effect of polyethylene glycol on the properties of Self-Curing Concrete", International Journal of Engineering and Technology(UAE) - IJET ISSN-2227-524X, 7 (3.29) (Aug 2018) pp. 519-532

5. K Satya Sai Trimurty Naidu, M V Seshagiri Rao and **V Srinivasa Reddy** (2018), “Analytical Model For Predicting Stress-Strain Behaviour Of Bacterial Concrete” International Journal of Civil Engineering and Technology (IJCIET), Volume 9, Issue 11, November 2018, pp. 2383–2393

6. M V Jagannadha Kumar, B Dean Kumar, K Jagannadha Rao and **V Srinivasa Reddy** (2018), "Effect of polyethylene glycol on the properties of Self-Curing Concrete", International Journal of Engineering and Technology(UAE)-IJET ISSN-2227-524X, 7 (3.29) (Aug 2018) pp. 519-532

CONFERENCE PROCEEDINGS:

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International Journal of Engineering & Technology

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Research paper

Mix proportioning of M80 grade Self-Compacting Concrete based on Nan Su Mix design method principles

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Abstract

The quest for the development of high strength and high performance concretes has increased considerably in recent times because of the demands from the construction industry. High-performance concretes can be produced at lower water/powder ratios by incorporating these supplementary materials. Fly ash addition proves most economical among these choices, even though addition of fly ash may lead to slower concrete hardening. However, when high strength is desired, use of silica fume is more useful. This paper proposes a mix proportions for M80 grade Self-compacting concrete (SCC) based on Nan Su mix design principles. First, the amount of aggregates required is determined, and the paste of binders is then filled into the voids of aggregates to ensure that the concrete thus obtained has flowability, self-compacting ability and other desired SCC properties. The amount of aggregates, binders and mixing water, as well as type and dosage of superplasticizer (SP) to be used are the major factors influencing the properties of SCC. Slump flow, V-funnel, L-flow, U-box and compressive strength tests were carried out to examine the performance of SCC, and the results indicate that the Nan Su method could produce successfully SCC of high strength. Based on Nan Su mix design method, material quantities such as powder content (Cement + Pozzolan), fine aggregate, coarse aggregate, water and dosages of SP and VMA, required for 1 cu.m, are evaluated for High strength grade (M80) of Self Compacting Concrete (SCC) are estimated. Final quantities, of M80 grade SCC mix, is assumed after several trial mixes on material quantities computed using Nan Su mix design method subjected to satisfaction of EFNARC flow properties.

1. Introduction

Self-compacting concrete (SCC) is a new kind of high performance concrete (HPC) with excellent deformability and segregation resistance. It is a special concrete that can flow through and fill the gaps of reinforcement and corners of moulds without any need for vibration and compaction during the placing process. To produce SCC, the major step is designing an appropriate mix proportion and evaluating the properties of the concrete thus obtained. In 1993, Okamura proposed a mix design method for SCC. The major advantage of this method is that it avoids having to repeat the same kind of quality control test on concrete, which consumes both time and labor. However, the drawbacks of Okamura's method are that (1) it requires quality control of paste and mortar prior to SCC mixing, while many ready-mixed concrete producers do not have the necessary facilities for conducting such tests and (2) the mix design method and procedures are too complicated for practical implementation. The ‘‘Standardized mix design method of SCC’’ proposed by the JRMCA is a simplified version of Okamura's method. This method can be employed to produce SCC with a large amount of powder materials, and a water/binder ratio of < 0.30. On the other hand, the Laboratory Central DesPontset Chausses (LCPC), the Swedish Cement and Concrete Research Institute (CBI), research groups in both Mainland China and Taiwan all have proposed different mix design methods of HPC. The LCPC's approach is developed on the basis of the BTRHEOM rheometer and RENE LCPC software. It is difficult for others to adopt their method without purchasing the software. CBI's approach makes use of the relationship between the blocking volume ratio and clear reinforcement spacing to fraction particle diameter ratio. However, it is not clear how to carry out the critical tests because concrete mixed with coarse aggregates and paste only is susceptible to severe segregation. In Taiwan, the method proposed by Hwang et al. involves a densified mixture design algorithm, which is derived from the maximum density theory and excess paste theory. Nevertheless, there is no information yet concerning the relationship between their method and the ability of concrete passing through reinforcement or its segregation resistance. Hon's group of Mainland China has not disclosed their mix design procedures, but just offered some useful principles. They have also shown that too low a paste volume not only impairs the passing ability of concrete, but also reduces its compression strength if no vibration is used in the mixing process. Hence forth this study tried to utilize Nan Su mix design procedure for SCC. The procedures are given below.

2. SCC Mix design Calculations for High Strength (M80) Grade SCC using Nan Su Mix Design

The following is the mix design for high strength grade (M80) is based on Nan Su mix design method.
Characteristic strength MPa 80
Target mean strength MPa 80 + 1.65 X 6 = 89.9
Aggregate size mm 10
Specific gravity of coarse aggregate 2.6
Bulk density of loose coarse aggregate kg/m3 1434
Specific gravity of fine aggregate 2.57
Bulk density of fine aggregate kg/m3 1474
Volume of fine / coarse aggregate ratio 50 / 50
Volume ratio of fine aggregate to total aggregates (s/a) 50 / 100=0.50
Determination of fine aggregates kg/m3
Assume P.F = 1.10
Ws = content of fine aggregate in SCC (kg/m3)
Ws = P.F.X Wsl X (1 – s/a) = 1.10 x 1434 x 0.5 kg/m3 810
Determination of coarse aggregate kg/m3
Wg = content of coarse aggregate in SCC (kg/m3)
Wg = P.F. X Wgl x (1-s/a) = 1.10 x 1434 (1-0.50) = 788 788
Determination of cement content
C = 89.9/0.14 = 89.9 / 0.14 = 644 Kg/m3 644
Determination of the mixing water content require by cement
Wwc = 0.24 x 644 = 154.56 kg/m3 154.56 L
W/Fly ash = 0.22 W/MK = 0.22
Determination of total pozzolanic material(100% fly ash):
Vpf + Vpmk = 1 – [Wq/1000 x Gg + Ws/1000 x Gs + Wc / 1000 x Gc + Wwc/1000 x Gw + 0.015]

= 1 – [788/1000 x 2.6 + 810/1000 x 2.57 + 644/1000 x 3.15 + 154.5/1000 x 1 + 0.015] = 0.008 kg/m3

Total weight of pozzolanic material (100% fly ash) (Wpm)
Wpm = (Vpk + Vpmk) x 1000 x 2.15 / (1 + W/F)
= 0.008 x 1000 x 2.15/ (1 + 0.22) = 14 kg/m3
Determination water required for Fly ashWwf = W/F x Wpm
= 0.22 x 14 = 3.1 kg/m3
S.P dosage = 1.8 % (644 + 14) = 11.84 Kg/m3
Water content in S.P. = (1-0.4) x 11.84= 7.10 Kg/m3
Total Water content = 154.56 + 3.1-7.10= 150.56 kg/m3
Water Binder ratio (W/B) = 150.56/ (644 + 14)= 0.23

Based on calculations from Nan Su mix design method, quantities required for 1 cu.m are evaluated for high strength grade (M80) blended Self-Compacting Concrete (SCC) made with Fly Ash (FA), Microsilica (MS).

Table 1 Quantities per 1 cu.m for M80 grade SCC obtained using Nan Su method:

	Cement	Total Pozzolana	Fine Aggregate	Coarse Aggregate	S.P	Water
		Fly ash				
Quantity kg/m^3	644	14	810	788	11.84 L	150.56 L

Final quantities are assumed after several trial mixes on quantities computed using Nan Su mix design method subjected to satisfaction of EFNARC flow properties as shown in Table 2. The following are the quantities of materials calculated using Nan Su mix design method for High strength grade (M80) of fly ash based Self Compacting Concrete (SCC) and also presented are final quantities of materials after various trial mixes.

Table 2 Final quantities after different trial mixes of high strength M80 grade SCC mix

	Cement	Total Pozzolana	Fine Aggregate	Coarse Aggregate	S.P.	Water (water/powder =0.25)
		Fly ash				
Quantity kg/m^3	450	250	714	658	12.21 L	167L

The computed amount of total powder (i.e., OPC+FA) is 658 kg. For the above quantities flow properties are achieved conforming to EFNARC guidelines. But keeping in view, the high quantity of cement computed using Nan Su method , the maximum cement content is limited to 450 kg per cum of concrete as per clause 8.2.4.2 of IS 456-2000. After trail mixes, revised quantities in kg per cu.m for high strength grade (M80) SCC mix are arrived by increasing quantity of Pozzolan (fly ash) to maximum amount without compromising the EFNARC flow properties and desired strength property. For higher grades, Nan Su mix design method computations yield very less powder content. In fact, from the observations it may be stated that Nan Su method is very difficult to apply for higher grades of concrete to arrive at appropriate quantities of materials.

3. Conclusions

1. The aggregate Packing factor determines the aggregate content and influences the strength, flow ability and self-compacting ability.
2. SCC designed and produced with the Nan Su mix design method contains more sand but less coarse aggregates, thus the passing ability through gaps of reinforcement can be enhanced.
3. In the Nan Su mix design method, the volume of sand to mortar is in the range of 54–60%.
4. The water content of SCC prepared by the Nan Su mix design method is about 167 $kg/m^3$for the high strength compressive strength.
5. The amount of binders computed in the Nan Su mix design method can be less than that required by other mix design methods due to the increased sand content.
6. The Nan Su mix design mix design method is simpler, requires a smaller amount of binders, and saves cost.
7. The Packing Factor for M80 grade is 1.1
8. Because SCC produced with this method contains less coarse aggregates, further studies are needed to evaluate its effect on the elastic modulus of concrete.

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Research Paper

Development of quaternary blended high performance concrete made with high reactivity metakaolin

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Abstract

In the last three decades, supplementary cementitious materials such as fly ash, silica fume and ground granulated blast furnace slag have been judiciously utilized as cement replacement materials as these can significantly enhance the strength and durability characteristics of concrete in comparison with ordinary Portland cement (OPC) alone. Hence, high-performance concretes can be produced at lower water/powder ratios by incorporating these supplementary materials. One of the main objectives of the present research work was to investigate synergistic action of binary, ternary and quaternary blended high strength grade (M80) concretes on its compressive strength. For blended high strength grade (M80) concrete mixes the optimum combinations are: Binary blend (95%OPC +5% FA, 95%OPC +5% MS and 95%OPC +5%MK), ternary blend (65%OPC+20%FA+15%MS) and quaternary blend (50%OPC+28%FA+11%MS+11%MK). Use of metakaolin in fly ash based blended concretes enhances compressive strength significantly and found to be cost effective in terms of less cement usage, increased usage of fly ash and also plays a major role in early strength development of fly ash based blended concrete.

Keywords: *high performance Concrete, Metakaolin, Fly ash, quaternary blended concrete, high strength concrete..*

1. Introduction

One of the effective methods to conserve the Mother Nature's resources and also reduce the environmental impact is to use Supplementary Cementitious Materials (SCMs) by substituting OPC partly or totally in concrete. Since most of SCMs are pozzolanic in nature and hence they are helpful in increasing later strength of concrete [1][2][4]. Blending of SCMs with cement has many advantages such as saving in cement, utilization of industrial by-products, enhancement of micro structural properties of concrete and reduces environmental impact through reduced greenhouse gases production. Most of the SCMs are industrial by-products which are considered as waste and pollutants when dumped into land or thrown into water bodies. So blending them in concrete becomes safe disposal method for them. Such SCMs are Fly ash (FA), Ground Granulated Blast furnace Slag (GGBS), Micro Silica(MS) or Silica Fume(SF), Copper slag (CS), Rice Husk Ash (RHA) etc.[3]

2. Objectives of the Present work

The primary objectives of this research work is to quantitatively comprehend and assess the role of optimum metakaolin (MK) in development of strength in binary, ternary and quaternary blended concrete, made with optimal micro silica and fly ash, of High strength grade (M80).

3. Experimental Investigations

The aim of the present experimental investigations is aimed to obtain specific experimental data which helps to understand the effect of synergic action of Metakaolin (MK), Microsilica (MS) and fly ash (FA) combinations in blended concrete mixes of high strength grade (M80) on rheological behavior and strength. The experimental programme consisted of casting and testing specimens of high strength grade (M80) of binary, ternary and quaternary blended concretes made with Fly Ash (FA), Microsilica (MS) and Metakaolin (MK). Erntroy and shaklock empirical mix design was adopted to arrive at the suitable mix proportions and final quantities for the binary, ternary and quaternary blended concrete based on a number of trial mixes.
To accomplish the defined objectives, the scope of the work is framed into phases:
Phase 1: Physical and Chemical Properties of Materials Used

a) Studies on physical and chemical properties of cement, coarse aggregate, fine aggregate (river sand), mixing water.

b) Studies on physical and chemical properties of mineral admixtures such as fly ash, metakaolin, silica fume and that of chemical admixtures such as Superplasticizer.

Phase 2: Determination of Mix Proportions
Based on Entroy and Shacklock's empirical graphs, material quantities such as powder content (Cement + Pozzolan), fine aggregate, coarse aggregate, water and dosages of SP, required for 1 cu.m, are evaluated for High strength grade (M80) of concrete. Final quantities, for the above grade of concrete mixes considered, are assumed after several trial mixes on material quantities computed.
Phase 3: Optimization of pozzolans in concrete mixes
In the first part of this phase, based on the assumed final material quantities in Phase 2, the optimum proportions of fly ash (FA), micro silica (MS) and metakaolin (MK) combinations in binary, ternary and quaternary blended concrete mixes, that attain desired strength property, are identified through several trial mixes carried

out in the laboratory for the grade considered for study.[5][6][7][8][9]&[10].

Phase 4: Studies on Compressive Strength

Compressive strengths at 3, 7, 28 and 60 days were determined by conducting detailed laboratory investigations on high strength grade (M80) made with optimum quantities of FA, MS and MK combinations in binary, ternary and quaternary blended concrete mixes.

4. Materials Used

4.1 Cement

Ordinary Portland cement (OPC) of 53 grade [IS: 12269-1987, Specifications for 53 Grade Ordinary Portland cement] has been used in the study.

4.2 Fine Aggregates (River Sand)

The fine aggregate used was locally available river sand without any organic impurities and conforming to IS: 383 – 1970.

4.2 Coarse Aggregate

The coarse aggregate chosen for blended concrete was typically round in shape, crushed granite metal of size of 20 mm and 10 mm graded obtained from the locally available quarries was used in the present investigation.

4.4 Water

Water used for mixing and curing was potable water, which was free from any amounts of oils, acids, alkalis, sugar, salts and organic materials or other substances that may be deleterious to concrete or steel confirming to IS : 3025 – 1964 part22, part 23 and IS : 456 – 2000 [Code of practice for plain and reinforced concrete].

4.5 Fly Ash

Fly ash used in this investigation was procured from Vijayawada Thermal Power Station, Andhra Pradesh, India. It confirms with grade I of IS: 3812 – 1981 [Specifications for flyash for use as pozzolana and admixture].

4.6 Micro silica (MS)

Micro silica Grade 92D conforming to IS: 15388 -2003 is used.
Silica fume has specific surface area of about 20,000m^2/kg.

4.7 Metakaolin (MK)

Metakaolin obtained from KOAT manufacturing company, Vadodara, Gujarat has been used.

4.8 Super Plasticizer (SP)

For M80, BASF Glenium B233, High-performance super plasticizer based on PCE (polycarboxylic ether) for concrete conforming to IS: 9103-1999 is used as a water-reducing admixture.

5. Mix Proportioning

The mix proportioning was done based on the Erntroy and shaklock mix design approach for high strength grade (M80) of binary , ternary and quaternary blended concretes made with optimum combinations of fly ash (FA), microsilica (MS) and metakaolin(MK). Several trial mixes are conducted on number of blended concrete mixes made with the different possible combinations of Fly Ash (FA), Microsilica (MS) and Metakaolin (MK) to develop various binary, ternary and quaternary blended concrete systems to determine the appropriate optimized quantities of Fly Ash.

6. Test Results and Discussions

The test results of experimental investigations carried out during the development of high strength grade (M80) binary, ternary and quaternary blended concrete mixes made with optimum proportions of fly ash (FA), microsilica (MS) and metakaolin (MK) combination are tabulated in the following sections. Quantities required for 1 cu.m are evaluated for high strength grade (M80) binary, ternary and quaternary blended concretes made with optimum proportions of Fly Ash (FA), Microsilica (MS) and Metakaolin (MK) combination based on calculations from Erntroy and shacklock mix design method. Final quantities, for all blended concrete mixes considered, are assumed after several trial mixes on quantities computed

Table 1. Quantities in kg per cu.m for high strength (M80) grade blended concrete obtained using Erntroy and shacklock Mix Design

	Cement	Fine Aggregate	Coarse Aggregate	Water
Quantity kg/m^3	700	644	966	150 L

The computed amount of OPC is 700 kg. But keeping in view the clause 8.2.4.2 of IS 456-2000, the maximum cement content is limited to 450 kg per cum of concrete. After trail mixes, revised quantities in kg per cu.m for high strength grade (M80) blended concrete mix are arrived without compromising the desired strength property.

The final quantities for high strength M80 grade blended concrete mix are tabulated in Table 2.

Table 2: Final Quantities for trial mixes of high strength M80 grade blended concrete mix

	Cement	Total Pozzolana	Total Powder Content	Fine Aggregate	Coarse Aggregate	Water (water/powder =0.23)
Quantity kg/m^3	450	250	700	644	966	150L

Henceforth, the total amount of powder quantity (cement + pozzolanic mixture) adopted for high strength M80 concrete is 700 kg/m^3 and water/powder ratio is 0.23 for all blended high strength M80 concrete mixes.

6.1 Optimization of SCMs proportions in blended concrete mixes

This phase identifies the optimum proportions of fly ash, micro silica and metakaolin in binary, ternary and quaternary blended concrete mixes in order to obtain the enhanced performance of blended concrete at all ages. The details of the quantities of materials, replacement percentages and quantities (kg) of SCMs and OPC in total powder content and their corresponding fresh properties are shown in Table 3 to Table 4 respectively for high strength grade (M80) of binary, ternary and quaternary blended concrete made with optimum proportions of Fly Ash (FA), Microsilica (MS) and Metakaolin (MK) combination.

Table 3 gives base quantities of high strength grade (M80) blended concrete mix derived after several trial mixes on the quantities calculated using Erntroy and shacklock mix design method. It can be observed that the total powder content is 700 kg/m3 with cement content restricted to 450 kg/m3 from durability of concrete point of view and rest of the powder is fly ash (250 kg/m3). Depending on the above calculated base quantities for high strength grade (M80), twenty nine (29) blended concrete mixes were designed in three groups of binary, ternary and quaternary. Table 2 shows various blended high strength grade (M80) blended concrete mixtures made with different proportions of Fly Ash (FA), Microsilica (MS) and Metakaolin (MK). In Mix designation, number indicates percentage by weight of total powder content. Various binary, ternary and quaternary blended concrete mixes were prepared with different proportions of Fly Ash (FA), Microsilica (MS) and Metakaolin (MK). (B1 to B8, T1 to T8 and Q1 to Q12). Mix numbers B1 to B8 are binary blended concrete mixtures made of either fly ash (FA) or microsilica (MS) or metakaolin (MK) while Mix numbers T1 to T8 are ternary blended fly ash based concrete mixtures made of microsilica (MS) or metakaolin (MK) and Mix numbers Q1 to Q12 are quaternary blended fly ash based concrete mixtures made of microsilica (MS) and metakaolin (MK) combination.

In high strength grade (M80) concrete mix ‘C1’ developed with 100% OPC does not yield desired strength. So using 100% OPC in development of high strength grade (M80) concrete mix is completely ruled out. In binary blended high strength grade (M80) concrete mixtures, percentage replacement of fly ash by weight of total powder content is 35% i.e. 250 kg/m3 (B1) which is based on preliminary calculation from mix design. For the mix proportion C65+FA35, desired strength is not realized. For binary blended concrete mixtures made with percentage replacement of either micro silica (MS) or metakaolin (MK) or both combined, micro silica (MS) and metakaolin (MK) are limited to 5-15% and 5-20% respectively.

In ternary blended micro silica (MS) and fly ash (FA) blended high strength grade (M80) concrete mixtures (T1 to T4) percentage replacement of micro silica (MS) is limited to 5 -20% by weight of total powder content. Similarly in ternary blended metakaolin (MK) and fly ash (FA) blended high strength grade (M80) concrete mixtures (T5 to T8), percentage replacement of metakaolin (MK) is limited to 5 -20% by weight of total powder content. In both the above ternary blended MS+FA blended concrete and MK+FA blended concrete mixtures (T1 to T8), the cement content is kept constant (65% by weight of total powder content).

In binary blended high strength grade (M80), for fly ash (FA) blended concrete mix (B1) and metakaolin (MK) blended concrete mixes (B5 to B8) desired strength is not realized. But in binary blended micro silica (MS) blended concrete mix, desired strength is attained, if the MS percentage replacement is limited to 5-10% by weight of powder. The optimal mix chosen for binary blended micro silica (MS) based concrete mix is 5% MS replacement (B2). Henceforth, for high strength grade (M80) mixes, Mix OPC95+MS5 (B2) is taken as reference mix.

In ternary blended metakaolin (MK) and fly ash (FA) blended high strength grade (M80) concrete mixtures (T5 to T8), desired strengths are not obtained for any of the mixes. But for micro silica (MS) and fly ash (FA) blended ternary blended concrete mixes (T1 toT4), up to 15% MS by weight of powder, desired strengths are attained satisfactorily. So C65+FA20+MS15 (T3) concrete mix is considered optimal in ternary blended high strength grade (M80) concrete mixes.

In quaternary blended high strength grade (M80) concrete mixtures (Q1 to Q12) made of microsilica (MS) and metakaolin (MK) combination, keeping cement content constant (65% by weight of total powder content), microsilica (MS) and metakaolin (MK) proportions are limited to 7 – 14%.

For quaternary blended concrete mix (Q1), initially 7% MS and 7% MK replacements are assumed, keeping cement content constant i.e. 65% by weight of total powder content and rest of powder is fly ash, and required workability is not satisfied. So microsilica (MS) and metakaolin (MK) are gradually increased to 14% each yet workability is not achieved. Then author proposed to additionally increase fly ash content incrementally by 10% by weight of powder content (700 kg/m^3), thereby incrementally increasing the powder quantity by 70 kg. With addition of 30% of fly ash (FA) to the C65+FA7+MS14+MK14 concrete mix (Q11), required workability and strength properties are achieved. So for quaternary blended concrete mix, the optimum combination of cement and pozzolanic mixture is revised as C50+FA28+MS11+MK11 concrete mix where final total powder content is 910 kg/m^3 in which cement content is 455 kg/m^3 and pozzolanic mixture is 455 kg/m^3.

Table 4 presents several possible binary, ternary and quaternary blended high strength grade (M80) concrete mixes with the quantities of pozzolanic mixtures, their flow properties and achieved strengths. From this table, three optimally blended concrete mixes are selected.

From the experimental investigations, the mixes B2, T3 and Q11 are chosen as optimum binary, ternary and quaternary blended high strength grade (M80) concrete mixes made with fly ash (FA), microsilica (MS) and metakaolin (MK) where both desired workability and strength properties are met along with optimal usage of pozzolanic quantities. The following are mix designations of optimum combinations of binary, ternary and quaternary blended high strength grade (M80) desired mixes:

(1) C95+MS5 [B2]
(2) C65+FA20+MS15 [T3]
(3) C50+FA28+MS11+MK11 [Q11]

Numbers in the above mix designations indicate percentage by weight of total powder content. Total powder content for binary, ternary is 700 kg/m3 and while for quaternary blended high strength grade (M80) it is 910 kg/m3. Thus, by incorporating metakaolin (MK) into micro silica (MS) and fly ash (FA) blended ternary blended desired mixes, the amount of fly ash used has almost doubled to achieve the requisite workability and therefore desired strength. From this observation, it can be understood that micro silica (MS) in blended desired mixtures imparts high strength but flow properties are marginally satisfied while metakaolin (MK) inclusion enhances the usage of high quantity of fly ash in blended concrete mixes for superior rate of gain of strength and more importantly for improved workability of concrete mix. The quaternary blended fly ash based concrete mix made of microsilica (MS) and metakaolin (MK) combination is found to be superior to ternary blended fly ash based concrete mix made with either microsilica (MS) or metakaolin (MK) due to reasons that for similar strength, better early strength, enhanced rate of gain of strength, improved flow properties and more use of fly ash quantity in developing blended high strength grade (M80) concrete.

Table 3. Base Quantities for high strength M80 grade concrete mix

	Cement	Fly ash	Total Powder Content	Fine Aggregate	Coarse Aggregate	Water (water/powder=0.23)
Quantity kg/m^3	450	250	700	644	966	150 L

Table 4 presents the summary of all the optimal quantities of binary, ternary and quaternary blended M80 grade concrete mixes. The table also displays the replacement percentages of SCMs, total powder content in kg and water/powder ratios along with corresponding mix numbers and mix designations

In high strength grade (M80), three optimally blended binary and ternary concrete mixes (C95+MS5, C65+FA20+MS15, C50+FA28+MS11+MK11) are chosen based on desired compressive strength achievement. From the studies, it is observed that without inclusion of micro silica (MS), desired high strength cannot be attained. Further investigations have showed that metakaolin (MK) based quaternary blended high strength concrete mix yield better performance than ternary and binary blends in terms of (1) usage of high quantity of fly ash, (2) enhanced fresh properties and (3) reduction in quantity of cement used.

From table 5.34and Fig 5.4, the total powder content for binary and ternary blended concrete mixes of high strength grade (M80) the total powder content adopted is 700 kg/m^3 and whereas for quaternary blended concrete mixes of M80 grade, the total powder content adopted is 910 (additionally 30% of FA is added). It can be concluded that quaternary blended concrete mixes are more efficient that ternary blended concrete mixes for high strength grade (M80).

Based on the compressive strength attained at specified age of curing, the efficacy of pozzolans are understood. In this study, pozzolans used for blended concrete mixes are Fly Ash (FA), Microsilica (MS) and Metakaolin (MK). Age of curing specified for Fly Ash (FA) blended binary, ternary and quaternary blended concrete mixes of various grades is 60 days while it is 28 days for Microsilica (MS) and Metakaolin (MK) blended concrete mixes.

Metakaolin (MK) blended concrete mixes will set relatively quickly due to its high reactivity, which also prevents bleeding and settling of aggregates.Metakaolin (MK) when compared to micro silica (MS) [10] has similar particle density and surface area but different morphology and surface chemistry. Because of its hydrophilic surface, Metakaolin (MK) is easier to disperse into wet concrete. Metakaolin (MK) can be incorporated at any stage of concrete production; it should be mixed thoroughly to achieve even distribution; intensive mixing is not necessary like micro silica (MS) based concrete

6.2 Studies on Compressive Strength of binary, ternary and quaternary blended concrete mixes

This investigation is carried out to study the compressive strength of binary, ternary and quaternary blended concrete mixes of high strength grade (M80) made with Fly Ash (FA), Microsilica (MS) and Metakaolin (MK) at 3,7,28 and 60days.

Table 6 presents the compressive strength of binary, ternary and quaternary blended concrete mixes of high strength grade (M80) made with Fly Ash (FA), Microsilica (MS) and Metakaolin (MK).

7. Conclusions

Based on the systematic and detailed experimental study conducted on high strength grade (M80) of binary , ternary and quaternary blended Concrete mixes made with fly ash (FA), microsilica (MS) and metakaolin (MK) with an aim to develop high performance concrete mixes, the following are the conclusions arrived.

1. Metakaolin blended binary, ternary and quaternary concrete mixes attain early strengths due to its inherent faster reacting capability than microsilica (MS) blended concrete mixes.
2. For development of high strength concrete mixes (M80), use of micro silica is compulsory due to its inherent high reactive property and micro-filler capacity.
3. In development of high strength (M80) grade fly ash blended concrete mixes, both metakaolin and micro silica are required to be added to leverage the benefits of micro-filler capacity of micro silica and early strength attainment of metakaolin. Addition of metakaolin (MK) to blended concrete mixes will enhance early hydration because of it high reactivity.
4. Optimally blended high strength grades M80 quaternary concrete mixes made of should be compacted 50%OPC+28%FA+11%MS+11%MK yields both required workability and desired compressive strengths. From this observation, it can be understood that micro silica (MS) in blended concrete mixtures imparts high strength while metakaolin (MK) inclusion enhances the usage of high quantity of fly ash in concrete mixes for superior rate of gain of strength. So it is evident that both metakaolin and micro silica are required in blended concrete mixes made with low water/powder ratio.
5. From the above observations it can be assumed for better flow and strength realization, in high strength grades (M80) blended fly ash based concrete mixes, the optimum percentage use of metakaolin is found to be 11%.
6. Compressive strengths of metakaolin blended binary, ternary and quaternary concrete mixes have slightly increased than non-metakaolin blended concrete mixes. Metakaolin cementing reaction rate is very rapid, significantly increasing compressive strength before first three days, which can have various benefits in fast paced construction industry.
7. Metakaolin (MK) is highly reactive alumina silicate whereas micro silica (MS) is reactive silicate. Hence Metakaolin (MK) supplemented concrete mixes have high strengths at all ages because silica and alumina present in Metakaolin (MK) reacts with CH forms CSH (pozzolanic reaction) and CAH (aluminate hydration) respectively which contributes to additional strength than micro silica (MS). So quaternary blended concrete mix made with micro silica (MS) and Metakaolin (MK) has improved microstructure which is dense and impermeable.

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Table 4– Trail mixes of high strength grade (M80) blended concrete mixes

Mix No.	Mix Designation (Values indicate percentage by weight of 'P'	Replacement % (bwp)*				Addi-tional % of FA bwp*	Quantities kg per cu.m				Total Pow-der Con-tent 'P'	Slump mm	Achieved Strength (MPa)
		OPC	FA	MS	MK		OPC	FA	MS	MK			
C1	C100	100	-	-	-	-	700	0	-	-	700	50	72.35
B1	C65+FA35	65	35	-	-	-	450	250	-	-	700	66	58.94
B2	C95+MS5	95	-	5	-	-	665	-	35	-	700	50	108.56
B3	C90+MS10	90	-	10	-	-	630	-	70	-	700	31	106.04
B4	C85+MS15	85	-	15	-	-	595	-	105	-	700	18	88.32
B5	C95+MK5	95	-	-	5	-	665	-	-	35	700	54	72,15
B6	C90+MK10	90	-	-	10	-	630	-	-	70	700	46	75.78
B7	C85+MK15	85	-	-	15	-	595	-	-	105	700	37	78. 82
B8	C80+MK20	80	-	-	20	-	560	-	-	140	700	48	69.35
T1	C65+FA30+MS5	65	30	5	-	-	455	210	35	-	700	55	81.23
T2	C65+FA25+MS10	65	25	10	-	-	455	175	70	-	700	55	94.20
T3	C65+FA20+MS15	65	20	15	-	-	455	140	105	-	700	55	100.54
T4	C65+FA15+MS20	65	15	20	-	-	455	105	140	-	700	46	78.91
T5	C65+FA30+MK5	65	30	-	5	-	455	210	-	35	700	54	76.23
T6	C65+FA25+MK10	65	25	-	10	-	455	175	-	70	700	52	77.34
T7	C65+FA20+MK15	65	20	-	15	-	455	140	-	105	700	51	78.12
T8	C65+FA15+MK20	65	15	-	20	-	455	105	-	140	700	43	67.21
Q1	C65+FA21+MS7+MK7	65	21	7	7	-	455	147	49	49	700	44	90.88
Q2	C60+FA28+MS6+MK6	65	21	7	7	10	455	217	49	49	770	54	82.34
Q3	C54+FA34+MS6+MK6	65	21	7	7	20	455	287	49	49	840	55	72.17
Q4	C65+FA14+MS14+MK7	65	14	14	7	-	455	98	98	49	700	41	80.16
Q5	C59+FA22+MS13+MK6	65	14	14	7	10	455	168	98	49	770	54	81.23
Q6	C54+FA28+MS12+MK6	65	14	14	7	20	455	238	98	49	840	54	83.65
Q7	C50+FA34+MS11+MK5	65	14	14	7	30	455	308	98	49	910	55	71.37
Q8	C65+FA7+MS14+MK14	65	7	14	14	-	455	49	98	98	700	33	90.94
Q9	C58+FA16+MS13+MK13	65	7	14	14	10	455	119	98	98	770	52	93.25
Q10	C53+FA23+MS12+MK12	65	7	14	14	20	455	189	98	98	840	54	94.72
Q11	C50+FA28+MS11+MK11	65	7	14	14	30	455	259	98	98	910	55	110.71
Q12	C46+FA34+MS10+MK10	65	7	14	14	40	455	329	98	98	980	56	79.91

Table 5 - Final optimized mix proportions of blended concrete mixes

Gradeof concrete Mix	Mix No	Mix Designation (Values indicate percentage by weight of 'P'	Replacement % (bwp)*				Additional % of FA bwp*	Quantities kg per cu.m								
			OPC	FA	MS	MK		OPC (i)	FA (ii)	MS (iii)	MK (iv)	Total Powder Content 'P' kg (i)+(ii)+ (iii)+(iv)	Fine Aggregate	Coarse Aggregate	Water	W/P ratio
M80	B2	C95+MS5	95	-	5	-	-	665	-	35	-	700	644	966	150	0.23
	T3	C65+FA20+MS15	65	20	15	-	-	455	140	105	-	700	644	966	150	0.23
	Q11	C50+FA28+ MS11+MK11	65	7	14	14	30	455	259	98	98	910	644	658	150	0.23

bwp* – By weight of Total Powder Content
W/P ratio – Water/Powder Ratio

Table 6 – Compressive Strengths of optimally blended M80 grade concrete mixes

Grade of concrete Mix	Mix No	Mix Designation (Values indicate percentage by weight of Total Powder)	Compressive Strength (MPa)			
			3 days	7 Days	28 days	60 days
M80	B2	C95+MS5	35.43	57.56	108.56	111.22
	T3	C65+FA20+MS15	26.18	50.12	73.17	100.54
	Q11	C50+FA28+MS11+MK11	50.02	64.19	95.26	110.71

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STUDIES ON DURABILITY PROPERTIES OF HIGH STRENGTH SELF-COMPACTING CONCRETE –A REVIEW

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ABSTRACT

Concrete industry is the largest consumer of natural resources. Carbon dioxide emission during the production of cement is the major concern which encourages concrete technologists to find for other means to reduce carbon footprint during the manufacturing concrete. Fly ash is the industrial by-product which needs an effective system for its disposal due to its serious environmental issue. It is a well-known fact that the use of fly ash in concrete is regarded as most efficient way of enhancing the durability of concrete. This paper reviews the research findings on the use of high volume fly ash in self-compacting concrete and its engineering properties. It is reported that the high volume fly ash self compacting concretes have shown less chloride ion permeability when compared to the normal concrete. It has also been investigated that the water absorption and sorpitivity have reduced with the addition admixtures as cement replacement.

Keywords: SCC, HVFA, Mineral Admixtures, Fly Ash, Durability.

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1. INTRODUCTION

As per ACI 237R-07, "Self-compacting concrete (SCC) is a highly flowable, non-segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any mechanical vibration". The definition of SCC includes properties that are related to the fresh state of the concrete. Terminology such as flowable, segregation resistant, and fill refer to standardized tests that have been developed with definable quantitative measurements and suggested ranges as **EFNARC** Guidelines. An important aspect of the SCC fresh concrete quality control tests is that these can be satisfied by a combination of standardized tests, namely the slump flow, J-ring flow, L-box, U-box, V funnel and the air content tests.

2. HIGH VOLUME FLY ASH (HVFA) CONCRETE

High volume fly ash (HVFA) concrete has been typically defined as concrete mixtures that contain more than 30% fly ash by mass of cementitious material **(Volz et al. (2012); Naik et al. (1995)**. Other authors have defined HVFA concrete mixtures as having more than 50% fly ash by mass of cementitious material with a low water content of w/cm <0.40 **(Reiner and Rens)(2006).**

Fly ash, as a replacement to cement is being used widely in recent years as it is environmental friendly, and percentage of replacement has been increasing day by day.More than 50% replacement of cement by fly ash in mass concrete has been reported by **S.A. Kristiawan and M. T. M. Aditya (2015)[1], H. Y. Leung, J. Kim et al. (2016) [2],P. Jiang, L. Jiang et al. [3].**Some research works have shown that the performance of concrete can be significantly increased by using mineral admixtures and also by using some industrial bi-products

Malhotra (1985)[4] has concluded that at 50% replacement of fly ash with cement, the concrete is exhibiting adequacy to be workable, low heat of hydration and low heat of hydration with enough early and later strengths. It can also be understood that such concrete makes strong solid framework for normal concrete and other mass concrete works. But the data availability for understanding the durability properties is sparse **T. Yen, C. Tang, C. Chang, and K. Chen (1999([5],K. Auenaert and G. De Schutter(2003)[6].**Essentially SCC consists of high volume of paste and high quantity of mineral admixtures when compared with the conventionally vibrated and compacted concrete.Use of large quantity of fine materials can impart cohesiveness to the SCC.

3. REVIEW OF THE LITERATURE

The literature available on the long term durability properties of SCC is very limited, hence authors reviewed and presented the research findings of various researchers on long term properties of SCC like permeability, drying shrinkage, carbonation depth, freezing and thawing, effect of deicing salts, water sorpitivity and sulphate attack as follows-

3.1. Drying Shrinkage

Yuvaraj LBhirud, Keshav KSangle (2017)[7]have investigated three mixes, one conventional vibrated concrete (NC), another Viscosity Modifying Agent (VMA) type Self compacting concrete (SCC) and the other powder type self-compacting concrete were prepared with same water-cement ratio. They found that shrinkage of normal concrete and VMA type SCC was observed to be identical and the shrinkage of SCC (550 kg/m^{3}of binder content) wasreported more. Observed values for NC and VMA-SCC are matching with predictions by ACI 209 R-92 whereas shrinkage for powder type SCC observed is more than prediction.

Hossain and Lachemi(2010)[8] have studied by replacing cement with volcanic ash (VA) from 20% to 50% and concluded that drying shrinkage of concrete with low water binder ratio and high volume of volcanic ash is increasing with age. The drying shrinkage strain was more for SCC with no volcanic ash added when compared to VA-SCC mixes.

Bouzoubaa and Lachemi(2001)[9]have studied nine SCC mixtures with fly ash upto 60%. They used class F fly ash and total cementitious material was constant at 400kg/m^3 and at the same time water to cementitious material varied from 0.35 to 0.45.The drying shrinkage strains were measured to assess the durability performance of SCC mixes with high volumes of fly ash. There was no difference found between the drying shrinkage strain of SCC and that of the control concrete. The drying shrinkage strain of the normal concrete was 5.41×10^{-4} at 224 days, and while SCC mixes ranged from 5.04×10^{-4} to 5.95×10^{-4} at 224 days.

Papayianni et al., 2011 [10] has experimented Self compacted concrete by replacing cement with calcareous fly ash in various proportions up to 50%.The assessment of durability in terms of shrinkage has been carried out. The High calcium fly ash SCC mixes have shown low early shrinkage deformation when compared with mixes without fly ash. It has also been concluded that the fly ash incorporation in SCC mixes have shown reduced early shrinkage deformations in terms of autogenous and plastic.

GopinathaNayak et al.(2015) [11]studied the effect of class F fly ash on properties of SCC. Ordinary Portland cement was replaced with 30% to 70% Fly ash in SCC. Water to binder ratio was maintained at 0.325 for all SCC mixes.Dryingshrinkage values were 30% lesser when compared tonormal concrete. The concrete mixes prepared with super plasticizer exhibited high rate shrinkage values.Shrinkage values were of up to 50% more incomparison with the concrete produced with no super plasticizer.

J.M. Khatib (2008)[12] studied the effect of Fly ash and admixture dosage on SCC. The results showed that huge quantity of Fly ash can be used in SCC to obtain high strength and low drying shrinkage. There was a considerable reduction in drying shrinkage as the fly ash quantity increases and at 80% FA content, the drying shrinkage at 56 days decreased by 0.66 times compared with the control concrete.

3.2. Permeability

The significant characteristic of durability properties of concrete is permeability. According to **Berry and Malhotra (1986)** [13] impervious concrete is more durable. **Joshi and Lohtia (1997)** [14] stated that durability of concrete is improved when the concrete is impermeable. Water content, aggregate grading, cementitious materials and curing are the factors that influence the permeability of concrete. The pozzolanic property of fly ash makes it react chemically with calcium hydroxide and water to produce CSH gel and the risk of leaching is considerably reduced. Considerable pore refinement takes place due to the presence of fly ash .Due to pozzolanic reaction between Portland cement paste and fly ash, the expansive pores changeover to fine pore, because of which the penetrability in cementitious frameworks decreases.

Bremner and Thomas (2004)[15] of ACI Committee 232, 2004 reported that durability of concrete is enriched when fly ash is an ingredient in concrete as the permeability is reduced because of no attack by aggressive agents. Oxygen permeability, hydraulic permeability and chloride permeability are the three majorindexes for permeability evaluation. The various methods for estimating the permeability of concrete are mentioned in various codes AASHTO T259 [16], ACI 228.2R-98 [17], API RP 27 [18], ASTM C1202 [19]

Bouzouba et al. (2000)[20] has developed six High volume fly ash mixes and the results of the resistance test to chloride ion penetration shows improvement at 14 and 28 days due to the crushing time of fly ash that improved its fineness and brought a compact microstructure of the paste in concrete in comparison to the concrete made with ungrounded fly ash.

Malhotra and Mehta (2002) [21] reported that the permeability of high volume fly ash (HVFA) concrete is less than normal conventional concrete with a water cement ratio of 0.4.

Amrutha et al.(2011) [22] has made five SCC mixes with high volume fly ash and results are compared for the durability performance with the normal vibrated concrete of similar strength. Self compacting concrete mixes with high volumes of fly ash were assessed by accelerated chloride permeability tests (RCPT) after different periods of curing. Based on the results, at 28 days curing, the RCPT values were less than 1000 coulombs and for normally vibrated concrete the current is in the range of 1800 to 2000 coulombs by which the range is considered as low to moderate, as per **ASTM C1202** [23]. It has been concluded that in aggressive and chloride rich environment SCC mixes with high volume fly ash performed well. The Chlorides infiltrate into cement by dispersion along the water movement pores. For such dispersion, the imperviousness is enhanced by redefining the pore structure of the solid. Also the response of tricalcium aluminates with fly ash makes SCC more impermeable.

Pathak and Siddique 2012 [24] have made studies by using fly ash as replacement in concrete and the specimens are cured at the temperature varying from 100 to 300°C. Rapid chloride penetration Test (RCPT) was carried out at 28, 91 and 365 days and the permeability of chloride ion reduced to 1000 to 2000 coulomb after 28 days for SCC mixes with fly ash. Usually with the rise in temperature the self compacting concrete becomes permeable, but is stable up to 100°C.

Dinakar et al. 2013 [25] have conducted studies on fresh and hardened properties of fly ash replaced self compacting concrete by replacing fly ash up to 70%. They have also made studies on durability properties namely chloride permeability, water absorption and water penetration depth. It is concluded that initial absorption value exhibited by self compacting concrete with fly ash was 3% but it has increased for self-compacting concrete with high volumes of fly ash. Further the penetration depths reported were higher at 50 and 70 %replacement levels.

3.3. Carbonation Depth

Turk et al.(2013) [26]experimented and investigated the carbonation depth of fly ash SCC, vibrated normal concrete and SCC with only cement. The carbonation resistance of Self compacting concrete with high volume of fly ash was higher than that of normal concrete. The carbonation resistance of Self compacting concrete with fly ash specimens decreased with the increase of silica fume and fly ash content. **J Khunthongkeaw, S Tangtermsirikul, and TLeelawat(2006)** [27] **and J Bai, S Wild, and B BSabir (2002)** [28] who have made similar studies also obtained the same results. This is because the concentration of the carbonation constituents of cement (CH and CSH) decreases due to the replacement of fly ash and silica fume by which concrete carbonation accelerates **V GPapadakis (2000) (29).** The carbonation depth of Self-compacting concrete specimens with 40% fly ash replacement was the highest in SCC mixes for all accelerated carbonation periods. These findings are the same as that reported by many researchers.**M I Khan and C JLynsdale (2002) [30], A M Paillere, MRaverdy, and G Grimaldi (1986) [31], D W S Ho and R K Lewis (1983) [32], H Shi, B Xu, and XZhou (2009) [33], K Byfors (1985) [34] and H Yazici (2008) [35].**

3.4. Freezing and Thawing

HalitYazici(2008) [36] has investigated on self-compacting concrete with 30% to 60% replacement of fly ash. The mechanical properties and durability performance of this concrete was assessed in terms of freeze & thaw and chloride ion penetration. The compressive strength results showed 7% loss after 90 cycles of freeze-thaw. Similar results have been announced by **Xie et al. (2002)** (37) after 100 cycles of freeze-thaw. When compared with compressive strength, split tensile strength is getting influenced by freeze-thaw effect.

3.5. Mechanical Properties

Manu Santhanam et al. (2007) (38) has made studies on mechanical properties of High strength self compacting concrete replaced by class F fly ash in different percentages of 0, 10, 30, 50, 70, 85 and compared with five different grades of normally vibrated concrete.All the mixtures were tested to get the fresh concrete properties in terms of stability and viscosity. Also after the hardened concrete specimens are ready, they are tested for strength properties such as compressive strength and mechanical properties such as elastic modulus test It has been observed that large amount of class F fly ash utilization gave reduced compressive strength results at 28 days but the strength at 90 days and 180 days showed greater improvement which is may be because of the pozzolanic reaction of fly ash. The split tensile strength exhibited by the self compacting fly ash concrete is more compared to that of normal concrete but lower elastic modulus when compared with normal concrete.

Vijin Xavier et al. (2015) (39) has studied the development of blended self compacting concrete by using fly ash in the percentage of 0-30% and metakaolin in the percentage of 0-30% byweight of cement and concluded that 15% fly ash and 15% metakaolin mixesare good in achieving target strength and also economical.

R Venkatakrishnaiah and GSakthivel (2015)[40] has carried out experimental work on three SCC mixes of M40 grade, the first set of mix contains 50% of cement replacement with fly ash, the second set of mix is made by admixing 20% of GGBS and 50% of fly ash as a replacement to cement, the third set of mixes containing 50% fly ash, 20% GGBS and 5% of silica fume. It has been observed that the cube compressive strength test results, chloride ion penetration test results and saturated water absorption test results are very good and the performance of all the three sets of mixes is satisfactory.

Gopinath et al. (2015) (41) has made a study to find the effect of class F fly ash on different properties of SCC. Portland cement is replaced in different percentages ranging from 30% to 70% in SCC and fresh properties along with hardened properties are studied. They could conclude that SCC mixes developed the compressive strength ranging from 26 to 48 MPa at 28 days. Also the drying shrinkage strain decreased with increase of fly ash content.

3.6. Sulphate Attack

Nehdi et al. 2004(42) has carried out experimental work to find the durability of Self compacting mixtures with high volume replacement of fly ash, slag and Rice husk ash. The sulfate expansion for various mixes cured for 9 months in 5% solution of Na_2SO_4 shown that the largest surface expansion was observed by the control SCC mix with 100% Portland cement where as the minimum expansion is realized in the mix with 50% OPC+24% fly ash+20% slag and 6% rice husk ash. Also in comparative studies, the authors analyzed and observed notably that the nine months expansion for 50% OPC+ 50% fly ash mix SCC was more than all other SCC mixes which contain slag. The sulfate ion penetration reduces in case of specimen made with ternary cementitious blends in comparison to binary cementitious blends. This is attributed to the low permeability characteristics of slag cement. Further, investigation is needed to evaluate this antagonistic effect.

4. CONCLUSION

The present review of literature shows the possibility of designing high strength SCC with high volume fly ash replacement taking a step towards eco- friendly and sustainable concrete practices. Also high volume fly ash blended cement can be manufactured with clinkers of cement and fly ashes that have a variety of chemical and physical structures. It is also observed that such cements are conforming to ASTM standards. The review related to cement replacement with fly ash shows that there is a change in properties like compressive strength, split tensile strength and flexural strength. It can be noticed that fly ash concretes possess enhanced durability than that of normal concrete. The self compacting concrete with high volume fly ash replacement has shown lower chloride ion permeability than normal concrete. The previous research studies indicate that the chloride penetration depth of SCC mixes with fly ash replacement is less than that of SCC with 100% ordinary Portland cement. High volume fly ash replacement is performing better thanconventional SCC mixes in achieving long term durability characteristics. The SCC made with high volume fly ash replacement is going to be economical, eco- friendly and sustainable material having scope of further research and investigation for the emerging generation construction projects.

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DEVELOPMENT OF SELF-CURING CONCRETE USING POLYETHYLENE GLYCOL AS INTERNAL CURING AGENT

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ABSTRACT

Self-curing or internal curing is a process in which moisture present in the concrete is preserved for more effective hydration of cement and reduced self-desiccation. In this paper, Self-curing concrete of M20, M40 and M60 grades are developed using optimized dosage of polyethylene glycol as internal curing agent. Compressive, split-tensile and flexural strength properties of self-curing concrete mixes are evaluated and exhaustive cost analysis is made on internally and externally cured concrete for economic feasibility. The optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) for M20, M40 and M60 grades self-curing concrete are 1%, 0.5% and 0.5% respectively. There is a significant increase of about 5-20% in the compressive, split-tensile and flexural strength properties of self-curing concrete mixes when compared to normal externally cured concrete mixes for all the grades considered for study. This improvement may be attributed to the continuation of the hydration process as a result of continuous availability of water. This resulting in, lower voids and pores, and greater bond force between the cement paste and aggregate. It was found that there is significant cost saving ranging from Rs. 2500 -3000 per cubic meter of concrete if internally cured.

Key words: Self-Curing Concrete, Internal Curing, Polyethylene Glycol, Self-Desiccation, Cost Analysis.

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1. INTRODUCTION

Self-curing referred as Internal-Curing is a process of controlling the moisture loss from the concrete. Concrete curing methods are basically divided into two groups i.e. Water adding method and Water retaining method. The internal-curing technique is a part of water retaining method. There are two major methods available for internal curing of concrete. The first method uses saturated porous lightweight aggregate (LWA) to supply an internal source of water, which can replace the water consumed by chemical shrinkage during cement hydration. The second method uses hydrophilic materials in concrete which reduces the evaporation of water from the surface of concrete and also helps in water retention. In the present study, the second method is adopted. The use of hydrophilic materials in concrete controls the loss of water and also attracts moisture from the atmosphere which provides continuous curing to concrete. Some special type of materials used in the internal curing process are Lightweight Aggregate (LWA) (natural and synthetic, expanded shale), Super-absorbent Polymers (SAP) and SRA (Shrinkage Reducing Admixture) i.e., propylene glycol, polyvinyl alcohol, Paraffin Wax, Acrylic acid. Mixing water itself cannot help in complete hydration of cement paste whereas internal curing can provide the required amount of water for complete hydration and to maintain the high relative humidity (RH) which prevents self-desiccation. This mechanism produces hard, dense concrete and minimizes shrinkage cracking, thermal cracking.

2. PROBLEM STATEMENT

Proper curing of concrete structures is vital to meet performance and durability requirements. Curing allows incessant hydration of cement and subsequently continuous gain in the strength. Lack of proper moisture conditions virtually slows down the hydration of the cement. Hydration practically stops when the relative humidity within the pores falls below 80%. The conventional curing is achieved by external applied water after hardening of concrete. Self-curing or internal curing is a process of preserving moisture in concrete for more effective hydration of cement and reduction of self-desiccation [1]. When concrete is exposed to the arid environment, evaporation of water takes place therefore loss of moisture will reduce the initial water- cement ratio which will result in the incomplete hydration of the cement affecting the quality of the concrete. Evaporation in the initial stage leads to plastic shrinkage cracking and at the final stage of setting it leads to drying shrinkage cracking. So curing period and temperature are very important factors that affect the strength development rate [2]. At high temperatures, ordinary concrete loses its strength due to the formation of the cracks between two thermally incompatible ingredients, i.e., cement paste and aggregates. Continuous evaporation of moisture takes place from an exposed surface due to the difference in chemical potentials between the vapour and liquid phases. The chemical polymers added into the mix as self-curing agents primarily form hydrogen bonds with water molecules and reduce the chemical potential of the water molecules which in turn reduces the vapor pressure subsequently reducing the rate of evaporation from the surface. The mechanism of internal curing is to hold the preserved water content of concrete structures so that they do not require any additional water for curing purpose. It is found that one cubic meter of finished concrete requires about three cubic metre of curing water [3]. Providing water for external curing has some limitations such as availability of good quality water, lack of accessibility of the structure, limited water cement ratio used in high performance concrete. To counter the above concerns, internal curing is the most appropriate solution. When polyethylene glycol (PEG) is added to water it forms hydrogen bonds which reduces water evaporation from concrete subsequently increasing the cement hydration**.** Rate of hydration increases the amount of solid phase of the paste as water is consumed by chemical reactions of hydration. In addition, water adsorbed onto the surfaces of the solids in the hydration products keeps them saturated maintaining the relative humidity in the paste to evade the phenomenon of self-desiccation. When the relative humidity drops below 80 %, the hydration rate slows down and it becomes negligible when the internal relative humidity drops to 30 % [4].

3. PROJECT SIGNIFICANCE

In the present paper, Self-curing concrete of M20, M40 and M60 grades are developed using optimized dosage of polyethylene glycol as internal curing agent. Workability, water retention capacity, compressive, split-tensile and flexural strength properties of self-curing concrete mixes are evaluated and exhaustive cost analysis is made on internally and externally cured concrete. The effect of internal curing initiates immediately with the initial hydration of the cement, so that its benefits are witnessed at ages as early as 2 or 3 days [5].Internal curing is advantageous in low water–cement ratio (w/c) concretes because of the chemical shrinkage during hydration and its low permeability. Since the water incorporated into and adsorbed by the cement hydration products has a specific volume less than that of bulk water, a hydrating cement paste will imbibe water (about 0.07gmof water/1gmof cement) from available sources[6].While in higher w/c concretes, this water is often supplied by external (or surface) curing. In low w/c concretes, the permeability of the concrete is too low to allow the effective transfer of water from the external surface to the interior of concrete [7]. This is the major reason to justify the need for internal curing. If water can be dispersed uniformly throughout the concrete, it will be readily available to migrate to the surrounding cement paste and contribute for the hydration process as required. From the review of literature it is found that the influence of molecular weight and dosage of self-curing agents was not given due significance to study the efficiency of self-curing. This paper focusses on determination of the optimum dosage and the molecular weight of PEG to accomplish efficient self-curing of concrete by studying the water retention by loss /or gain of weight of the specimens. Manufacturing cost of externally cured and internally cured concrete mixes of various grades are also estimated to understand the economic viability.

4 MATERIALS AND MIX PROPORTIONS

4.1. Polyethylene Glycol

In this project, after several trials, Polyethylene glycol (PEG) of molecular weight 400 is chosen as self-curing agent. Polyethylene-glycol is a condensation polymer of ethylene oxide and water with the general formula $H(OCH_2CH_2)_nOH$, where n is the average number of repeating ox ethylene groups typically from 4 to about 180 [8].Polyethylene glycol 400 is strongly hydrophilic. After trials, it was found that polyethylene glycol (PEG) of lower molecular weight i.e., PEG 400 is more efficient as a self-curing agent when compared to the PEG of higher molecular weight. Increasing the molecular weight of polyethylene glycol also results in decreasing solubility in water [9] and also past literature reported that hygroscopic capacity decreases as molecular weight increases [10]. Table 1 shows the properties of PEG 400. Table 2 presents the quantities per cu.m. for various grades of concrete.

Table 1 Properties of PEG 400(Source: www.parchem.com)

Property Name	Property Value
Specific gravity	1.12 at 27°C
pH	>6
Molecular weight (gm/mol)	400
Appearance	Clear liquid
Colour	White
Hydroxyl value (mg KOH/gm)	300
Nature	Water soluble
Molecular formula	$H(OCH_2CH_2)_n OH$
Density g/cm^3	1.125

Table 2 Quantities per cu.m. for various grades of concrete

	Cement kg	Microsilica	Fine aggregate kg	Coarse aggregate kg	Water L	Super plasticizer L	Polyethylene Glycol (PEG) L
M20	320.4	-	727.3	1105.4	173.0	-	3.20
M40	390.7	-	776.0	1019.7	164.1	-	1.95
M60	436.0	27.8 (6% b.w.c)	779.9	1118.0	120.6	4.2	2.32

b.w.c – by weight of cement

5. RESEARCH FINDINGS

This section presents test results of various experimental investigations carried out on various grades of normal cured and self-curing concrete mixes.

5.1. Workability

Table 3 presents workability of various grades of concrete mixes incorporated with various dosages of Polyethylene Glycol (PEG 400).

Table 3 Workability of various grades of concrete mixes incorporated with various dosages of Polyethylene Glycol (PEG 400)

Polyethylene Glycol (PEG) Dosage (Percentage by weight of cement)	Slump in mm		
	M20	M40	M60
0 %	90	66	51
0.5 %	98	69	56
1%	108	77	62
1.5%	113	83	73
2%	121	95	77

Table 4 presents the compressive strengths of various grades of concrete mixes incorporated with various dosages of Polyethylene Glycol (PEG 400) at 28 days age of curing.

Table 4 Compressive strengths of self-curing concrete mixes made with various dosages of Polyethylene Glycol (PEG 400)

Polyethylene Glycol (PEG) Dosage (Percentage by weight of cement)	Compressive Strength at 28 days age of curing		
	M20	M40	M60
0 % (external curing)	26.90	48.25	68.38
0.5 %	27.40	**58.15**	**72.61**
1%	**31.18**	48.40	69.14
1.5%	26.40	47.60	68.97
2%	26.40	47.40	68.14

Figure 1 shows the optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) to be used in various grades of self-curing concrete.

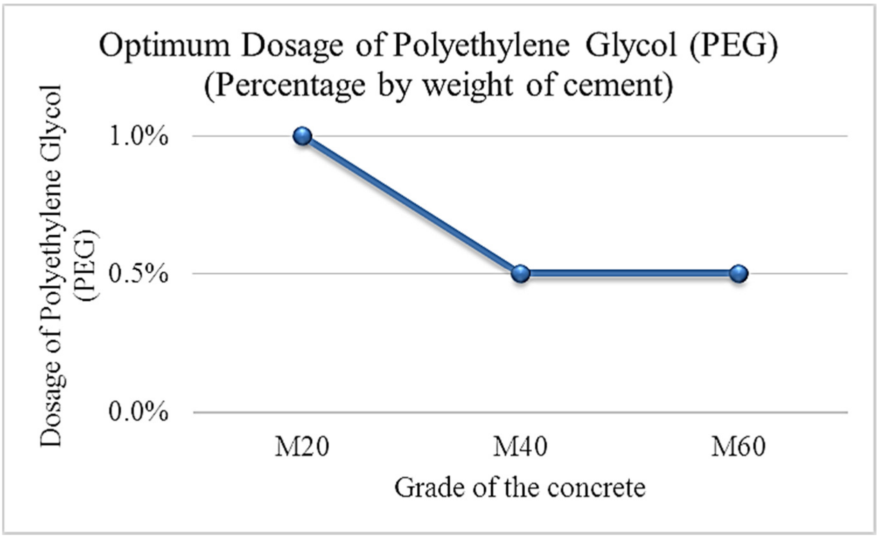

Figure 1 Optimum dosage of polyethylene glycol (PEG)

Table 5presents the Compressive, Split-tensile and Flexural strength properties of normal and self-curing concrete mixes at various ages of curing.

Table 5 Compressive, Split-tensile and Flexural strength properties of normal and self-curing concrete mixes at various ages of curing.

Type	Property	Grade of the concrete	Age of Curing				
			28 days	60 days	90 days	180 days	365 days
Normal Concrete (Water cured)	Compressive Strength (MPa)	M20	26.84	30.90	31.69	32.87	33.51
		M40	49.53	53.78	55.20	56.54	57.38
		M60	69.15	75.49	79.61	84.37	85.92
	Split Tensile Strength (MPa)	M20	3.10	3.18	3.32	3.50	3.52
		M40	4.30	4.41	4.66	4.83	4.87
		M60	4.41	4.49	4.68	4.87	4.89
	Flexural Strength (MPa)	M20	4.46	4.70	4.88	4.94	4.97
		M40	5.41	5.70	5.95	6.13	6.17
		M60	8.23	8.44	8.65	8.74	8.77
Self-curing Concrete (Air cured)	Compressive Strength (MPa)	M20	31.18	36.16	37.52	38.25	38.72
		M40	58.15	63.35	63.65	65.32	65.80
		M60	72.61	79.26	83.59	88.59	90.22
	Split Tensile Strength (MPa)	M20	3.55	3.70	3.85	4.01	4.03
		M40	4.89	5.15	5.38	5.49	5.50
		M60	5.36	5.54	5.65	5.70	5.73
	Flexural Strength (MPa)	M20	5.82	6.02	6.20	6.28	6.28
		M40	6.90	7.11	7.29	7.42	7.44
		M60	9.94	10.10	10.27	10.33	10.36

6. COST ANALYSIS

Manufacture cost of Normal concrete mixes in Rupees per cu.m is presented in Table 6.

Total cost incurred for Normal (externally cured) concrete in Rupees per cu.m.is presented in Table 7.Manufacture cost of Self-curing (Internally cured) concrete mixes in Rupees per cu.m. is presented in Table 8. Table 9 compares the rate incurred for externally and internally cured concrete mixes in Rupees per cu.m.

For external curing it was estimated that for one cu.m. of concrete at least 3 cu.m or 3000 Litres water is required. Time of application of water externally is about 8hr/day for 7 days continuously at Rs.400 per day as Labor charges.

Costs of materials are assumed based on market prices as follows:

1. Cement – Rs 6/kg;
2. Microsilica – Rs 22/kg;
3. Fine aggregate – Rs 1.8/kg and Coarse aggregate - Rs 0.70/kg;
4. Water- Rs 0.50/L;
5. Super plasticizer- Rs 40/kg;
6. Polyethylene Glycol (PEG 400)- Rs.544/L

Table 6 Manufacture cost of normal concrete mixes (Rs. per cu.m)

Grade of Concrete	Cement (a)	Microsilica (b)	Fine aggregate (c)	Coarse aggregate (d)	Water (e)	Super plasticizer (f)	Cost / cu.m. (a)+(b)+(c)+ (d)+(e)+(f)
M20	320.4 kg x Rs.6 = Rs.1922.40	-	727.3 kg x Rs.1.8 = Rs.1309.14	1105.4 kg x Rs.0.70 = Rs.773.78	173 L x Rs. 0.50 = Rs.86.50	-	**Rs.4091.82**
M40	390.7 kg x Rs.6 = Rs.2344.20	-	776 kg x Rs.1.8 = Rs.1396.80	1019.7 kg x Rs.0.70 = Rs.713.79	164.1 L x Rs. 0.50 = Rs.82.00	-	**Rs.4536.79**
M60	436 kg x Rs.6 = Rs.2616.00	27.8 kg x Rs.22 = Rs.611.60	779.9 kg x Rs.1.8 = Rs.1403.82	1118 kg x Rs.0.70 = Rs.782.60	120.6 L x Rs.0.50 = Rs.60.30	4.2 L x Rs.40 = Rs. 168.00	**Rs.5642.32**

Table 7 Total Cost of Normal (Externally Cured) Concrete per cu.m.

Grade of Concrete	Cost of Concrete per cu.m (a)	Cost of Water required for external curing of one cu/m. of concrete (b)	Cost of Extra labor required to apply the water externally (c)	Total cost incurred for externally cured Concrete per cu.m. (a)+(b)+(c)
M20	Rs.4091.82	3000 L x Rs.0.50 = Rs.1500	400 x 7 = 2800	**Rs.8391.82**
M40	Rs.4536.79	3000 L x Rs.0.50 = Rs.1500	400 x 7 = 2800	**Rs.8836.79**
M60	Rs.5642.32	3000 L x Rs.0.50 = Rs.1500	400 x 7 = 2800	**Rs.9942.32**

Table 8 Total Cost of Self-curing (Internally cured) concrete mixes (Rs. per cu.m)

	Cement (a)	**Microsilica (b)**	**Fine aggregate (c)**	**Coarse aggregate kg (d)**	**Water L (e)**	**PEG (f)**	**Super plasticizer L (g)**	**Cost / cu.m. (a)+(b)+ (c)+(d)+ (e)+(f)+(g)**
M20	320.4 kg x Rs.6 = Rs.1922.40	-	727.3 kg x Rs.1.8 = Rs.1309.14	1105.4 kg x Rs.0.70 = Rs.773.78	173 L x Rs. 0.50 = Rs.86.50	3.20 L x Rs.544 = Rs.1740.80	-	Rs.5832.62
M40	390.7 kg x Rs.6 = Rs.2344.20	-	776 kg x Rs.1.8 = Rs.1396.80	1019.7 kg x Rs.0.70 = Rs.713.79	164.1 L x Rs. 0.50 = Rs.82.00	1.95 L x Rs.544 = Rs.1060.80	-	Rs.5597.59
M60	436 kg x Rs.6 = Rs.2616.00	27.8 kg x Rs.22 = Rs.611.60	779.9 kg x Rs.1.8 = Rs.1403.82	1118 kg x Rs.0.70 = Rs.782.60	120.6 L x Rs.0.50 = Rs.60.30	2.32 L x Rs.544 = Rs.1262.08	4.2 L x Rs.40 = Rs.168.00	Rs.6904.40

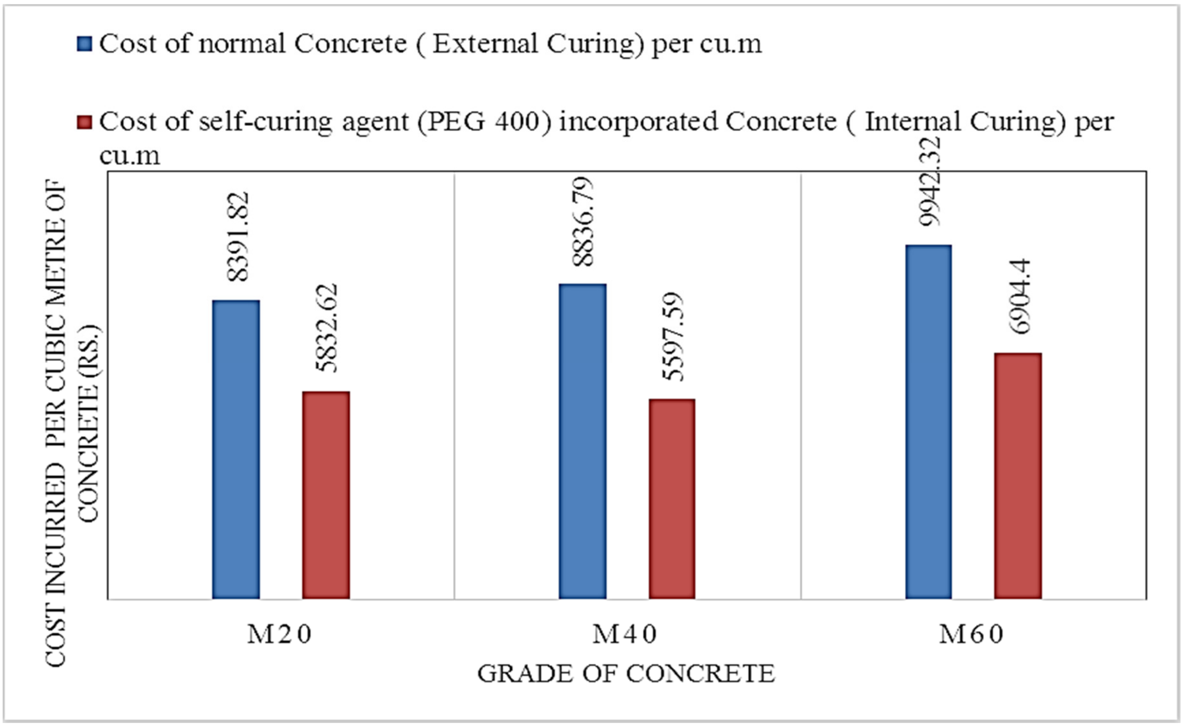

Figure 2 Cost comparison of externally and internally cured concrete per cu.m.

Table 9 Cost comparison of externally and internally cured concrete per cu.m.

	Cost of normal Concrete (External Curing) per cu.m	Cost of self-curing agent (PEG 400) incorporated Concrete (Internal Curing) per cu.m	Cost Saving
M20	Rs.8391.82	Rs.5832.62	Rs.2559.20
M40	Rs.8836.79	Rs.5597.59	Rs.3239.20
M60	Rs.9942.32	Rs.6904.40	Rs.3037.92

7. DISCUSSIONS

In the present study, M20, M40 and M60 grades of external water cured normal concrete specimens and air cured self-curing concrete specimens using optimized dosage of polyethylene glycol as internal curing agent are developed. It is observed that as grade increases workability decreases in self-curing concrete mixes. Similarly as dosage of polyethylene glycol (PEG) increases, workability increased. The optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) for M20, M40 and M60 grades self-curing concrete are 1%, 0.5% and 0.5% respectively.

There is a significant increase in the compressive, split-tensile and flexural strength properties of self-curing concrete mixes at all ages of curing when compared to normal externally cured concrete mixes of about 5-20% for the grades considered in this study. This improvement may be attributed to the continuation of the hydration process as a result of continuous availability of water resulting in, lower voids and pores, and greater bond force between the cement paste and aggregate as stated in the previous literature.

It is understood that, the role of self-curing agent polyethylene glycol is to reduce water evaporation from concrete, hence there is an increase in the water retention capacity of self – cured concrete, when compared with normal concrete, which leads to enhanced compressive strength. This improvement in strength is not only due to the ability of concrete to retain water which causes continuation of the cement hydration, but also due to the conversion of calcium hydroxide into CSH. This CSH formed on the surface of aggregate particles strengthens the aggregate-matrix transition zone which becomes less porous and more compact. The research findings of past researchers demonstrated that the PEG is affecting the bond between the aggregate particles and the cement paste. The region between the cement paste and aggregate particles is usually populated by massive crystals of CH, and it is generally believed that the nature of these crystals influences the strength of the cement paste-aggregate bond, which in turn affects the strength of the concrete as a whole. It has been previously reported by other researchers that the addition of the PEG has the effect of altering the morphology of CH in cement pastes. There is evidence from past literature that the PEG is altering CSH gel morphology. This appears to enhance the nature of the CSH gel, leading to better permeability characteristics.

Low dosage of polyethylene glycol is more efficient for achieving self-curing concrete when compared to the higher dosages. Polyethylene glycol of lower molecular weight is found to be more efficient as a self-curing agent when compared to the PEG of higher molecular weight.

In practice, for actual site conditions, the conventional concrete requires water for external curing as well as an extra labor to apply the water to the concrete for a minimum duration of 7days at 8hr/day whereas with the development of internally cured concrete the amount of water applied for external curing and its labor cost can be saved as there is no such requirement of curing in case of internal cured concrete. So an attempt was also made to find out the rates and compare the cost incurred for the normal concrete and internal cured concrete. It was found that there is significant cost saving ranging from Rs. 2500 -3000 per cubic metre of concrete if concrete is internally cured.

8. CONCLUSIONS

From the results obtained in this study the following conclusions can be noted:

- The use of self-curing agent (polyethylene glycol) in concrete mixes improves the strength properties of concretes under air curing regime which may be attributed to a better water retention and causes continuation of the hydration process of cement past resulting in less voids and pores, and greater bond force between the cement paste and aggregate.
- It is observed that as grade increases workability decreases in self-curing concrete mixes. Similarly as dosage of polyethylene glycol (PEG) increases, workability increased.
- The optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) for M20, M40 and M60 grades self-curing concrete are 1%, 0.5% and 0.5% respectively.
- There is a significant increase in the compressive, split-tensile and flexural strength properties self-curing concrete mixes at all ages of curing when compared to normal externally cured concrete mixes.
- It was found that there is significant cost saving ranging from Rs. 2500 -3000 per cubic metre of concrete if concrete is internally cured.

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ANALYTICAL MODEL FOR PREDICTING STRESS-STRAIN BEHAVIOUR OF BACTERIAL CONCRETE

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ABSTRACT

Bacillus subtilis, a mineral precipitating microorganism, when introduced into concrete produces calcium carbonate crystals which seals the micro cracks and pores in the concrete. This process imparts high strength and durability to bacteria treated concrete along with enhancement in other mechanical properties. In order to study one such mechanical property, the stress-strain behavior of bacterial concrete, appropriate analytic stress-strain model is established that capture the real (observable) behavior. In this paper, an attempt is made to develop a mathematical model for predicting the stress-strain behaviour of bacteria induced high strength concrete.

Keywords:-Bacterial concrete, stress-strain curves, Saenz model, Bacillus subtilis, toughness.

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1. INTRODUCTION

For decades, many researchers developed empirical and semi-empirical stress-strain relationships to describe the behavior of concrete in compression. The better the stress-strain model, the more reliable is the estimate of strength and deformation behavior of concrete structural members. The compressive stress-strain behavior of concrete is a significant issue in the flexural analysis of reinforced concrete beams and columns. The stress-strain curve of concrete is also useful for investigating the ductility of concrete. Moreover, the total area under the stress-strain curve can represent the amount of energy absorbed by the specimen under loading. A stress - strain curve is a graph obtained by plotting the values of stresses and strains obtained by testing cylinders of standard size made with concrete under uni-axial compression. It is observed from the stress-strain plots that, no portion of the curves is in the form of a straight line even though the stress strain relation for cement paste and aggregate when tested individually is practically linear. In concrete the rate of increase of stress is less than that of increase in strain because of the formation of micro cracks, between the interfaces of the aggregate and the cement paste. Thus the stress strain curve is not linear. In controlled concrete, the value of stress is maximum corresponding to a strain of about 0.002 and further goes on decreasing with the increasing strain, giving a dropping curve till it terminates at ultimate crushing strain. After obtaining the stress-strain behavior of controlled and bacterial concrete mixes experimentally, an attempt is made by validating it against the analytical stress-strain curves for controlled and bacterial concrete mixes.

2. METHODOLOGY

This paper mainly aims at utilizing the best attributes of earlier models and proposes a new stress-strain model that can well represent the overall stress-strain behavior of high strength bacterial concrete mixes. After obtaining the stress-strain behavior of controlled and bacterial concrete experimentally, empirical equations are developed to represent uni-axial stress-strain behavior of controlled and bacterial concrete mixes. From these empirical equations, theoretical stresses for controlled and bacterial concrete are calculated and compared with experimental values. The proposed equations have shown good correlation with experimental values validating the mathematical model developed. The proposed empirical equations can be used as stress block in analyzing the flexural behavior of controlled and bacterial concrete.

3. EXPERIMENTAL INVESTIGATIONS

In the present study, Stress-Strain behavior of controlled and bacterial concrete of high strength grades (M60 and M80) are studied. The test is carried out on cylindrical specimens of diameter 150 mm and height 300 mm. Total 12 cylinders of standard size are cast with the specified controlled and bacterial concrete mixes and tested in axial compression under strain control and stress-strain behavior is observed by plotting stresses against strains. The capped cylindrical specimen is attached with setup having two dial gauges and is placed on the movable cross head of the testing machine and centered correctly. The dial gauges having least count of 0.02mm is used. The specimen is placed in a computer controlled universal testing machine (UTM) of 3000 kN capacity. For satisfactory recording of strain, the cross head movement of 0.02 mm per second is suggested by the previous researchers. The specimens are tested under strain control under uni-axial compression as per IS : 516-1999 to get the stress-strain characteristics.

4. MATHEMATICAL MODELING FOR STRESS-STRAIN BEHAVIOUR

4.1. Mathematical Models available for Stress-Strain behaviour of Concrete

Many models were developed for the Stress-Strain behaviour prediction of concrete by many researchers. Some models are considered below.

4.1.1. Desayi's and Krishnan's Model (1964)

This model is a derivation from Saenz's original equation. For normal strength concrete, stress-strain relationship is given by

$$f = \frac{Ax}{1 + Bx^2}$$

Where f = The Normalized stress (f / f_o) ; x = Normalized strain ($\in / \in_o$) and A, B are the constants and they can be found out by using boundary conditions. This model is valid only to ascending portion of stress-strain curve.

4.1.2. Modified Saenz Model (1964)

Considering the limitation of analytical equation proposed by Desayi et al, Saenz proposed a model by taking into account both the ascending and descending portions of the stress-strain curve. This model is in the form of $y = \frac{Ax}{1 + Bx + Cx^2}$ Where $y = \sigma / \sigma_u$ and $x = \in / \in_u$

4.1.3. Hognestad Model (1955)

For Normal strength concrete up to ascending portion: The stress-strain model is $f_c = f_c^{'}\left\{2(\in / \in_o) - (\in / \in_o)^2\right\}$ where f_c' = compressive strength ; $\in_o$ = strain at peak stress = 0.0078 (f_c')$^{1/4}$

4.1.4 Wang et al, Model (1978)

The model used by Wang *et al.* is in the form of $f_c = f_c^{'}\left\{\frac{A(\in / \in_o) + B(\in / \in_o)^2}{1 + C(\in / \in_o) + D(\in / \in_o)^2}\right\}$

However instead of using one set of the coefficients A, B, C, and D to generate the complete curve, Wang *et al*, used two sets of coefficients – one for the ascending branch and the other to the descending branch. The respective coefficients being obtained from the relevant boundary conditions assigned to each part of the curve.

4.1.5 Carriera and Chu Model (1985)

This model is in the form of

$f_c = f_c^{'}\left\{\frac{\beta(\in / \in_o)}{\beta - 1 + (\in / \in_o)^{\beta}}\right\}$ In which $\beta = 1 - \left(f_c^{'} / \in_o E_{it}\right)$ where f_c'= cylinder ultimate compressive strength and $\in_o$ = strain at ultimate stress; E_{it} = Initial tangent modulus

4.2. Proposed Model for Stress-Strain behavior of bacterial concrete

Of all the above stress-strain models, simplified and the modified single variable polynomial equations based on modified Saenz's model that fits with developed normalized stress-strain curves seems to be valid for both ascending and descending portions of the curve. The developed equations for ascending and descending portions of analytical stress-strain curve are in the form of

$$y = \frac{Ax}{1 + Bx + Cx^2} \text{ And } y = \frac{Dx}{1 + Ex + Fx^2}$$

where y is the stress at any level ; x is the corresponding strain at that level; A, B, C are the constants for ascending portion and D, E, F are the constants for descending portion of analytical stress-strain curve. Similarly, the equations for ascending and descending portions of non-dimensional stress-strain curve are in the form of

$$f / f_o = A^1(\in / \in_o) \ / (1 + B^1(\in / \in_o) + C^1 (\in / \in_o)^2) \text{ and}$$

$$f / f_o = D^1 (\in / \in_o) + / (1 + E^1 (\in / \in_o) + F^1(\in / \in_o)^2)$$

A^1, B^1, C^1 are the constants for ascending portion and D^1, E^1, F^1 are the constants for descending portion of non-dimensional stress-strain curve. f / f_o is normalized stress(stress ratio) and $\in / \in_o$ is the normalized strain (strain ratio).Constants are evaluated based on the boundary conditions of normalized stress-strain curves for both controlled and bacterial concrete.

Boundary conditions for ascending and descending portions of stress-strain curves are,

(1) At the origin the ratio of stresses and strains are zero i.*e.* at $(\in / \in_o) = 0, (f / f_o) = 0$

(2) The strain ratio $(\in / \in_o)$ and stress ratio at the peak of the non-dimensional stress-strain curve is unity. i.*e* at $(\in / \in_o) = 1$, $(f / f_o) = 1$

(3) The slope of non-dimensional stress-strain curve at the peak is zero

i.*e* at $(\in / \in_o) = 1.0$, $d(f / f_o) / d(\in / \in_o) = 0$

(4) At 85% stress ratio, the corresponding values of strain ratio is recorded i.*e* at $(f / f_o) = 0.85$, $(\in / \in_o)$=strain ratio corresponding to 0.85 stress ratio where f_o - peak stress and $\in_o$ - strain at peak stress ; f and $\in$ corresponds to stress and strain values at any other point. Boundary conditions (1), (2) and (3) are for determining the constants A^1, B^1, C^1 in the ascending portion of the normalized stress-strain curve and (2), (3) and (4) are for determining the constants D^1, E^1, F^1in the descending portion of the curve.. Corresponding A, B, **C** constants for ascending portion and D, E, F constants for descending portion of analytical stress-strain curve are then evaluated using equations

$$A = A^1 \ (f_o \ / \in_o), \ B = B^1 (1/\in_o) \text{ and } C = C^1 (1/\in_o)^2$$

$$D = D^1 \ (f_o \ / \in_o), \ E = E^1 (1/\in_o) \text{ and } F = F^1 (1/\in_o)^2$$

Ultimately analytical equations giving the complete stress-strain behavior are developed for high strength grades of controlled and bacterial concretes.

4.3. Development of Analytical equations

The following tables present constants and Analytical equation for ascending and descending portions of non-dimensional stress-strain curve.

Table 1 Constants for ascending and descending portions of non-dimensional stress-strain curve

Grade of Concrete	Controlled Concrete						Bacterial Concrete					
	Ascending portion Constants			Descending portion constants			Ascending portion Constants			Descending portion constants		
	A^1	B^1	C^1	D^1	E^1	F^1	A^1	B^1	C^1	D^1	E^1	F^1
M60	1.20	-0.80	1	1.87	-0.13	1	0.56	-1.44	1	1.25	-0.75	1
M80	0.60	-1.40	1	1.87	-0.13	1	0.63	-1.37	1	1.51	-0.49	1

Table 2 Peak stress values and their corresponding strains

Grade of Concrete	Controlled Concrete		Bacterial Concrete	
	Peak Stress f_o	Corresponding strain at peak stress $\in_o$	Peak Stress f_o	Corresponding strain at peak stress $\in_o$
M60	72.61	0.0023	94.21	0.0023
M80	98.50	0.0020	113.00	0.0024

Table 3 Constants for ascending and descending portions of theoretical stress-strain curve

Grade of Concrete	Controlled Concrete					
	Ascending portion Constants			Descending portion constants		
	A	B	C	D	E	F
M60	37832	-326	189036	59096	-230	189036
M80	29998	-700	250000	92545	-65	250000
	Bacterial Concrete					
M60	23007	-539	189036	51057	-317	189036
M80	29693	-745	250000	71227	-365	250000

4.4. Calculation of Theoretical Stresses using proposed Analytical Equations

Theoretical stresses have been calculated using proposed empirical equations for controlled and bacterial concrete which are derived from modified Saenz's model in the form of

$$y = \frac{Ax}{1 + Bx + Cx^2} \text{ And } y = \frac{Dx}{1 + Ex + Fx^2}$$

Where y is the stress at any level; x is the corresponding strain at that level

After developing empirical equations for stress-strain curves of controlled and bacterial concrete, theoretical values of stresses are calculated at different values of strains in concrete based on the developed empirical equations. These theoretical stress-strain curves are compared with experimental stress-strain curves and found that, theoretical stress-strain curves have shown good correlation with experimental stress-strain curves for all grades of controlled and bacterial concrete mixes.

5. TEST RESULTS

The test results of the experimental investigations are presented below

Table 4 Experimental Stress - Strain values of High strength grade concrete (M60)

Controlled Concrete		Bacterial Concrete	
Strain	Stress, MPa	Strain	Stress, MPa
0	0	0	0
0.0001	3.27	0.0001	2.83
0.0002	6.41	0.0001	5.66
0.0003	9.01	0.0002	8.49
0.0004	12.98	0.0003	11.32
0.0005	15.32	0.0003	14.15
0.0006	18.65	0.0004	16.99
0.0007	21.10	0.0004	19.82
0.0008	24.55	0.0005	23.20
0.0009	28.56	0.0006	25.70
0.0010	36.00	0.0007	31.00
0.0011	38.80	0.0008	34.60
0.0012	42.30	0.0010	40.00
0.0014	47.60	0.0011	46.70
0.0016	61.00	0.0012	54.90
0.0023	72.61	0.0014	61.00
0.0027	65.70	0.0015	82.40
0.0033	36.80	0.0023	94.21
0.0034	30.30	0.0033	51.00
0.0035	29.15	0.0035	36.08

Table 5 Experimental Stress - Strain values of High strength grade concrete (M80)

Controlled Concrete		Bacterial Concrete	
Strain	Stress, MPa	Strain	Stress, MPa
0	0	0	0
0.0001	2.54	0.0001	2.11
0.0003	6.13	0.0001	3.06
0.0003	11.20	0.0002	4.50
0.0005	14.69	0.0003	7.11
0.0006	18.91	0.0003	9.08
0.0006	21.63	0.0004	13.33
0.0007	25.44	0.0004	18.64
0.0008	32.59	0.0005	25.54
0.0009	36.33	0.0006	36.11
0.0009	41.25	0.0007	40.99
0.0010	48.99	0.0008	53.28
0.0011	55.09	0.0010	61.01
0.0012	67.32	0.0014	81.30

0.0016	85.40	0.0016	94.10
0.0020	98.50	0.0018	104.40
0.0033	70.30	0.0022	107.40
0.0036	36.80	0.0024	113.00
0.0034	30.30	0.0036	41.60
0.0037	29.15	0.0038	20.20

Table 6 Experimental and Theoretical Stress - Strain values of High strength grade concrete (M60)

Controlled Concrete			Bacterial Concrete		
Strain	Experimental Stress, MPa	Theoretical Stress, MPa	Strain	Experimental Stress, MPa	Theoretical Stress, MPa
0	0	0	0	0	0
0.0001	3.27	3.91	0.0001	2.83	2.53
0.0002	6.41	8.02	0.0001	5.66	5.53
0.0003	9.01	12.29	0.0002	8.49	8.32
0.0004	12.98	16.66	0.0003	11.32	10.36
0.0005	15.32	21.06	0.0003	14.15	12.36
0.0006	18.65	25.41	0.0004	16.99	16.64
0.0007	21.1	29.65	0.0004	19.82	21.64
0.0008	24.55	33.7	0.0005	23.2	25.13
0.0009	28.56	37.5	0.0006	25.7	28.78
0.001	36	41	0.0007	31	32.54
0.0011	38.8	44.15	0.0008	34.6	36.34
0.0012	42.3	46.92	0.001	40	43.75
0.00134	47.6	51.31	0.0011	46.7	47.19
0.0016	61	59.5	0.0012	54.9	50.37
0.0023	72.61	69.6	0.0014	65.6	64.7
0.0027	65.7	65.3	0.00161	82.4	80.3
0.0033	36.8	47.24	0.0023	94.21	92.4
0.0034	30.3	42.3	0.0033	51	53.5
0.0035	29.15	34.4	0.0035	36.08	38.59

Table 7 Experimental and Theoretical Stress - Strain values of High strength grade concrete (M80)

Controlled Concrete			Bacterial Concrete		
Strain	Experimental Stress, MPa	Theoretical Stress, MPa	Strain	Experimental Stress, MPa	Theoretical Stress, MPa
0	0	0	0	0	0
0.0001	2.54	3.17	0.0001	2.11	2.53
0.0003	6.13	10.91	0.0001	3.06	5.53
0.0003	11.2	10.91	0.0002	4.5	7.32
0.0005	14.69	20.74	0.0003	7.11	10.36
0.0006	18.91	26.46	0.0003	9.08	11.36
0.0006	21.63	26.46	0.0004	13.33	14.64
0.0007	25.44	32.7	0.0004	18.64	21.64
0.0008	32.59	39.4	0.0005	25.54	25.13

0.0009	36.33	46.45	0.0006	36.11	38.78
0.0009	41.25	46.45	0.0007	40.99	32.54
0.001	48.99	53.73	0.0009	53.28	56.34
0.0011	55.09	61.04	0.001	61.01	63.75
0.0012	67.32	68.19	0.00112	68	68.2
0.0016	85.4	90.92	0.00139	82.1	84
0.0022	98.5	98.5	0.00176	100.5	94.2
0.00283	70.3	69.04	0.00202	109.7	103.8
0.00337	36.8	42.3	0.00243	113	109.3
0.00351	30.3	29.54	0.003	92.11	93.48
			0.0036	41.6	39.73

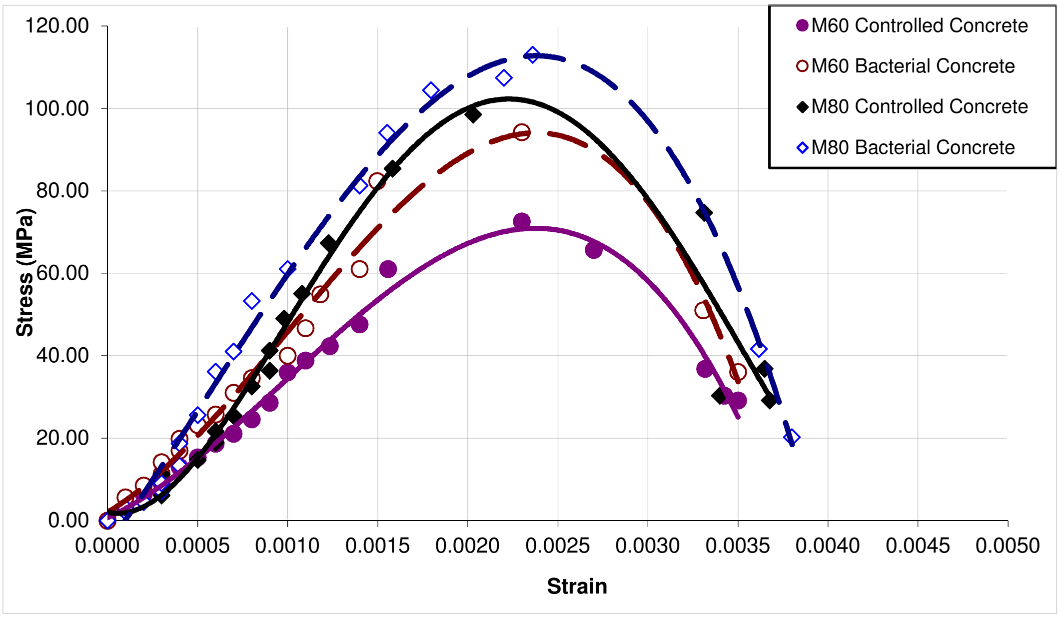

Figure 1 Stress- Strain Curves

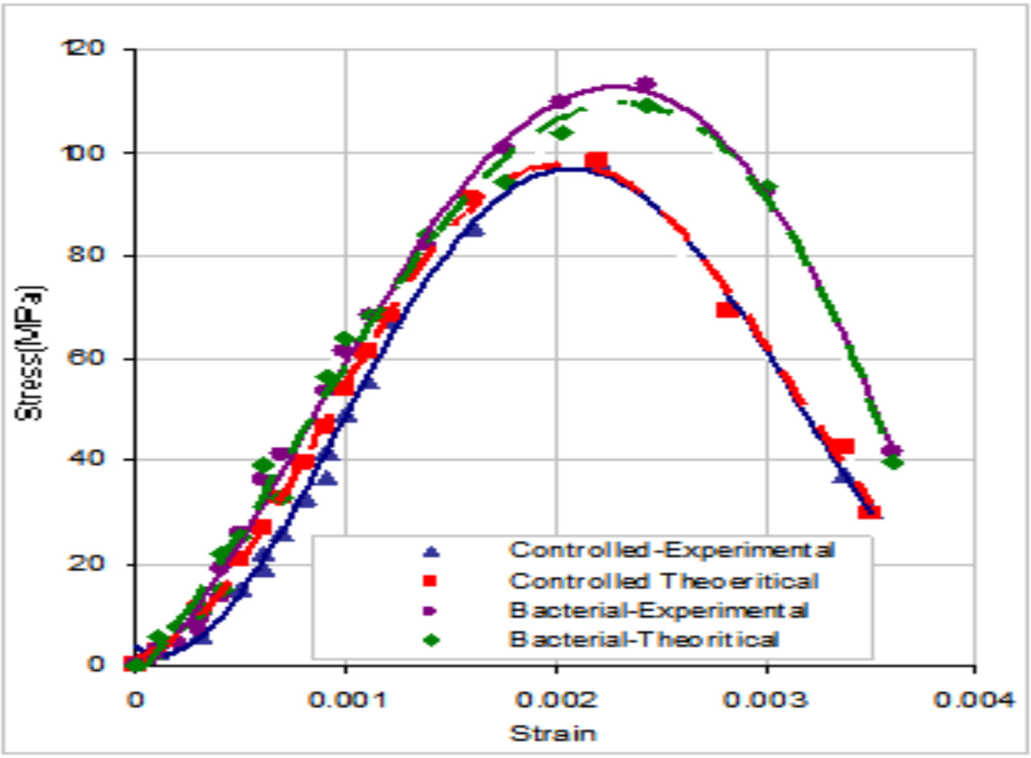

Figure 2 Graph showing Experimental and Theoretical stress strain values of controlled and bacterial concrete (M60 Grade)

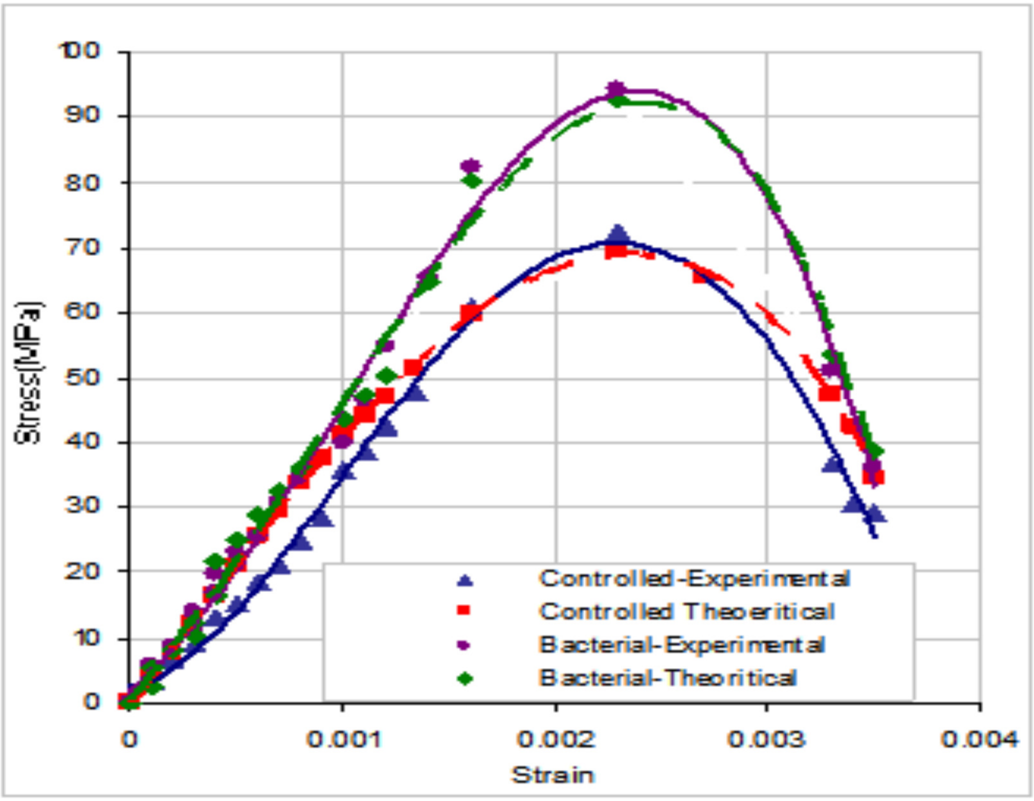

Figure 3 Graph showing Experimental and Theoretical stress strain values of controlled and bacterial (M80 Grade)

6. DISCUSSIONS

From experimental non- dimensional stress-strain data, the theoretical non-dimensional stress – strain data is generated. There is a good agreement in experimental and theoretical values which confirms the validation of proposed model adopted to study the stress-strain behaviour of controlled and bacterial concrete of high strength grades (M60 and M80). From the values of stresses and strains, stress-strain curve for each mix is plotted, taking the average values of the results of the three cylinders. From the stress-strain values of controlled and bacterial concrete mixes the corresponding normalized stress-strain values are calculated by dividing each stress value by the peak stress and dividing each strain value by strain at peak strain. From the normalized stress-strain values of controlled and bacterial concrete mixes, the average normalized stress-strain curves are plotted for controlled and bacterial concrete separately and empirical equations are proposed in the form of $y= Ax/(1+Bx+Cx^2)$ for ascending and descending portions of controlled and bacterial concrete mixes for high strength grades of concrete. Theoretical stresses are evaluated and compared with experimental stress values to found that there is very little variation which validates the proposed mathematical model. From the observations made from stress-strain curves of all the controlled and bacterial concrete mixes, the stress-strain behaviour is observed to be almost similar. The only difference is that bacterial concrete mixes have shown improved stress values for the same strain levels compared to that of controlled concrete mixes. It can be observed from stress-strain curves that for high strength concrete, the shape of the ascending part of the stress-strain curve is more linear and steeper, that results in the increase of elastic modulus. The strain at peak stress is slightly higher, and the slope of the descending part is steeper as compared to normal strength concrete. That was due to the decrease in the extent of internal micro cracking in higher strength concrete. In the uniaxial compression of concrete cylinders, the results show that the strain at peak stress of normal strength concrete is usually less than that of high performance concrete, modulus of elasticity of high performance concrete is higher than that of normal strength concrete behavior of controlled and bacterial concrete sections. For all different grades of controlled and bacterial concrete, the proposed equations have shown good correlation with experimental values. From the literature it appears that modified second degree polynomial as suggested by L.P. Saenz seems to be better fit with appropriate constants suitable for present curves

7. CONCLUSIONS

From the experimental results obtained throughout the course of this study, the following conclusions can be drawn as follows:

1. The Bacterial concrete mixes have shown improved stress values for the same strain levels compared to that of controlled concrete mixes in all high strength grades
2. Average values of strain at peak stress for controlled and bacterial concrete are very close to the value of strain at peak stress for controlled concrete in axial compression which is 0.002 as per IS 456-2000.
3. The analytical equations for the stress-strain response of controlled and bacterial concrete mixes have been proposed in the form of $y = Ax / (1+Bx+Cx^2)$, both for ascending and descending portions of the curves with different set of values for constants. The proposed equations have shown good correlation with experimental values.
4. The proposed empirical equations can be used as stress block in analyzing the flexural behaviour of sections of controlled and bacterial concrete.

5. The stress-strain curves obtained in the experiment for different grades of controlled and bacterial concrete exhibit a similar trend when compared to the empirical equations of modified Saenz model. So Saenz mathematical model is successfully evaluated and validated for bacterial concrete.

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Research paper

Effect of polyethylene glycol on the properties of self-curing concrete

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Abstract

Hydration of Portland cement directly effects the development of engineering properties of concrete. It is reported that for sufficient hydration to take place, the relative humidity in the pores needs to be maintained above 80%. It is very important to minimize the loss of moisture from concrete. Curing is the method of regulating the water content of concrete during cement hydration. The objective of this paper is to observe the effect of polyethylene glycol as internal curing agent, on the properties of self-cured concrete of M20, M40 and M60 grades. Compressive, split-tensile and flexural strength properties of self-curing concrete mixes are evaluated and assessment of the quality, structural integrity and compressive strength are made on internally and externally self-cured concrete. The optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) adopted for M20, M40 and M60 grades self-cured concrete are 1%, 0.5% and 0.5% respectively. There is a significant increase in the compressive, split-tensile and flexural strength properties self-curing concrete mixes at all ages of curing when compared to normal externally cured concrete mixes of about 5-20% for all the grades considered for study. This improvement could be due to continuous hydration process thus incessant availability of water resulting in less number of pores and voids and stronger bond between the aggregate and cement paste. Non-destruction evaluation studies reveal that all grades of self-curing agent induced concrete are classified as ‘excellent’ concretes in terms of strength and durability point of view due to improved concrete’s pore structure through enhanced hydration and strengthening of interface transition zone.

Keywords: *Self-Curing Concrete; Internal Curing; Polyethylene Glycol; Self-Desiccation; Non-Destructive Tests*

1. Introduction

For effective hydration of concrete,water should be provided for at least 28 days . Any negligence in curing will severely affect the strength and durability of the concrete. Self-curing concrete is a special concrete which offers a solution to mitigate the problem of insufficient curing caused due to human negligence,lack of water in parched areas, lack of accessibility of structures in hilly areas and salts present in the water which can affect the properties of concrete. We should minimize loss of moisture from concrete during early stage.If not the extent of hydration of cement decreases and effects the properties of concrete. [1]. Curing operations should be such that the required amount of water is continuously available for hydration. Curing plays an important role in strength and durability of concrete.Negligence in curing hampers hydration process. Curing and hydration will happen simultaneously. Continuous presence of moisture is required to maintain a R.H. of 80%. If R.H is less than 80% within the capillaries, the hydration stops. In normal curing, R.H is maintained at 80% by external application of water. Self-curing provides more moisture to concrete for perfect hydration of cement and minimizes self-dessication. Upon exposure to environment, evaporation of water leads to moisture loss. This will result in the decrease of water-cement ratio as per design mix which leads to incomplete cement hydration which affects quality of concrete. When the relative humidity is less than 80 %, the hydration rate slows down and it becomes negligible if the internal relative humidity is less than 30 %.

2. Principle of internal curing in concrete

Self Curing is a special concrete gaining importance due to inherit advantages. This type of concrete doesn't need curing some chemicals are added during mixing of concrete and these are responsible for continuous hydration of cement even if there is no external application of water. When PEG 400 is introduced in the mix,it forms hydrogen bonds with water molecules and hence chemical potential of water molecules is lowered. The fall in chemical potential results in reduction of vapour pressure and results in lowering of evaporation rate from surface.The principle of internal curing is to hold the preserved water content of concrete structures within it. So, concrete structures do not require any extra water for curing purposeWater soluble alcohols are generally used as self-curing agents. Internal curing is often referred to as ‘Self–curing’. Internal curing provides water to keep the relative humidity (RH) high, preventing self-desiccation from occurring [8]. The materials used as internal curing agents are:Expanded Shale, Propylene glycols like PEG 400 ,SRA (Shrinkage Reducing Admixture)
Self Curing Concrete has better hydration due to water retention compared to traditional concrete [10].

3. Project significance

In the present paper, Self-curing concrete of grades in three ranges M20, M40 and high strength M60 are developed using optimized dosage of polyethylene glycol as internal curing agent. Workability, Weight retention, Compressive, split-tensile and flexural strength characteristics of self-curing concrete mixes are evaluated and investigations are carried out to estimate the quality and properties like structural integrity and compressive strength using Rebound hammer and Ultrasonic pulse velocity tests.

4. Materials and mix proportions

4.1. Polyethylene glycol

In this project, Polyethylene glycol (PEG), a strongly hydrophilic substance having molecular weight of 400 is chosen as self-curing agent. Polyethylene-glycol is a polymer formed by the condensation between ethylene oxide and water,having the general formula H(OCH2CH2)n OH, where n being the average number of oxyethylene groups typically ranging from 4 to about 180. Table 1 shows the properties of PEG 400.

Table 1: Properties of PEG 400 (Source: Www.Parchem.Com)

Property	Value
Specific gravity	1.12 at 27□C
pH	>6
Molecular weight (g/mol)	400
Appearance	Clear liquid
Colour	White
Hydroxyl value (mg KOH/g)	300
Nature	Water soluble
Molecular formula	$H(OCH_2CH_2)_n$ OH
Density g/cm^3	1.125

Table 2: Presents the Quantities Per Cu.M. Of Different Grades of Concrete

Grade of Concrete	Cement kg	Microsilica	Fine aggregate kg	Coarse aggregate kg	Water L	Polyethylene Glycol (PEG) L	Super plasticizer L
M20	320.4	-	727.3	1105.4	173.0	3.20	-
M40	390.7	-	776.0	1019.7	164.1	1.95	-
M60	436.0	27.8 (6% b.w.c)	779.9	1118.0	120.6	2.32	4.2

5. Research findings

This section presents results of different experimental investigations held on different grades of traditional cured and self-cured concrete mixes.

Figure 1 shows the optimum dosage of PEG 400 (expressed in percentage by weight of cement) to be used in various grades of self-cured concrete.

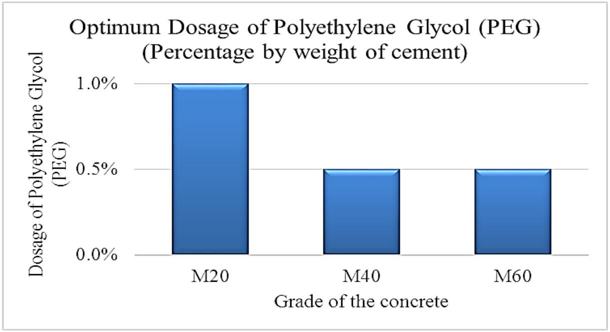

Fig. 1: Optimum Dosage of PEG 400 and Quantity in Litres per CU.M.

Table 3 exhibits the Water retention capacity of self-cured concrete mixes made with optimum dosages of Polyethylene Glycol (PEG 400) in terms of weight loss.

Table 3: Water Retention Capacity of Normal Air Cured and Self-Cured Concrete Mixes

Type	Grade of the concrete cube of size 100mm	Average Weight Loss with age in grams				
		0 days	3 days	7 days	14 days	28 days
Normal Concrete (Air cured)	M20	0	88	113	162	199
	M40	0	35	57	75	97
	M60	0	21	33	45	61
Self-cured Concrete (Air cured)	M20	0	9	17	25	38
	M40	0	6	16	21	28
	M60	0	4	10	17	23

Figure 2 presents the Compressive strength properties of normal and self-curing concrete mixes at 28 days age of curing. Table 4 presents the Compressive, Split-tensile and Flexural strength properties of normal and self-curing concrete mixes at various ages of curing.

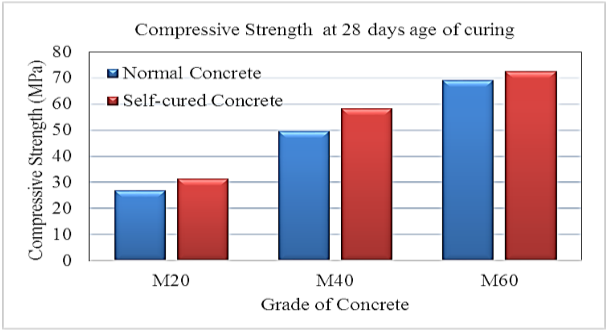

Fig. 2: Compressive Strength Properties of Normal and Self-Curing Concrete Mixes at 28 Days Age of Curing.

Table 4: Compressive, Split-Tensile and Flexural Strength Properties of Normal and Self-Curing Concrete Mixes at Various Ages of Curing.

Type	Property	Grade of the concrete	Age of Curing				
			28 days	60 days	90 days	180 days	365 days
Normal Concrete (Water cured)	Compressive Strength (MPa)	M20	26.84	30.90	31.69	32.87	33.51
		M40	49.53	53.78	55.20	56.54	57.38
		M60	69.15	75.49	79.61	84.37	85.92
	Split Tensile Strength (MPa)	M20	3.10	3.18	3.32	3.50	3.52
		M40	4.30	4.41	4.66	4.83	4.87
		M60	4.41	4.49	4.68	4.87	4.89
	Flexural Strength (MPa)	M20	4.46	4.70	4.88	4.94	4.97
		M40	5.41	5.70	5.95	6.13	6.17
		M60	8.23	8.44	8.65	8.74	8.77
Self-cured Concrete (Air cured)	Compressive Strength (MPa)	M20	31.18	36.16	37.52	38.25	38.72
		M40	58.15	63.35	63.65	65.32	65.80
		M60	72.61	79.26	83.59	88.59	90.22
	Split Tensile Strength (MPa)	M20	3.55	3.70	3.85	4.01	4.03
		M40	4.89	5.15	5.38	5.49	5.50
		M60	5.36	5.54	5.65	5.70	5.73
	Flexural Strength (MPa)	M20	5.82	6.02	6.20	6.28	6.28
		M40	6.90	7.11	7.29	7.42	7.44
		M60	9.94	10.10	10.27	10.33	10.36

This section presents experimental investigations to assess the quality and properties of self curing concrete like structural integrity and compressive strength of normal and self-cured M20, M40 and high strength M60 grade concrete mixes using Rebound hammer test and Ultrasonic pulse velocity measurements.

The Rebound Hammer Test is conducted as per IS: 13311 (Part 2) – 1992 on different grades of traditional and self-curing concrete cubes of size 150mm. This test mainly evaluates the quality of surface hardness based on the rebound numbers obtained. Table 5 and 6 presents criteria to determine quality of concrete surface as per IS: 13311 (Part 2) – 1992 and integrity and homogeneity of concrete as per IS: 13311 (Part 1) – 1992 respectively

Table 5: Quality of Concrete Based on Average Rebound Hammer

Average rebound number	Quality of concrete surface
> 40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
< 20	Poor

Ultrasonic Pulse Velocity Test is conducted as per IS: 13311 (Part 1) – 1992 on different grades of conventional and self-curing concrete cubes of size 150mm. This test qualitatively assesses the integrity and homogeneity of concrete. This test also determined the density and elastic properties of the concrete.

Table 6: Concrete Quality Based on USPV as Per IS: 13311 (Part 1) – 1992

Pulse velocity	Concrete quality
>4.5 km/s	Excellent
3.5 – 4.5 km/s	Good
3.0 – 3.5 km/s	Medium
<3.0 km/s	Doubtful

To make a more realistic assessment of the quality and integrity of concrete, a prudent approach of combined use of Non–destructive tests namely rebound hammer tests and ultrasonic pulse velocity were used. Mean rebound values and mean ultrasonic pulse velocities (USPV) are measured to understand the quality, integrity and strength of self-curing agent incorporated concrete and compare with normal concrete's corresponding properties.

The Table 7 lists the mean rebound values, mean pulse velocity values of different grades of self-curing agent incorporated and normal concrete specimens at 28 age of curing, along with their estimated compressive strengths.

Table 7: Combined Rebound Hammer and Ultrasonic Pulse Velocity Values of Various Grades of Normal and Self-Cured Concrete Mixes

Property	Grade of the concrete	Type of Concrete	
		Normal cured	Self-cured
Mean Rebound Number	M20	25	33
	M40	36	41
	M60	41	48
Mean Ultra sonic Pulse Velocity, km/s	M20	4.26	4.77
	M40	4.49	4.93
	M60	4.89	5.22
Estimated Compressive strength, MPa	M20	28.18	32.74
	M40	51.19	60.17
	M60	72.61	74.21
Quality	M20	Good	Excellent
	M40	Good	Excellent
	M60	Excellent	Excellent

6. Discussions

In the current study, influence of polyethylene glycol as internal curing agent on characterstics of M20, M40 and high strength M60 grades of concrete mixes is evaluated The optimum dosage of polyethylene glycol (PEG) (expressed in percentage by weight of cement) for M20, M40 and M60 grades self-cured concrete are found to be 1%, 0.5% and 0.5% respectively based on the maximum compressive strength attainment. There is a considerable increase in the compressive, split-tensile and flexural strength properties of self-curing concrete mixes of about 5-20% when compared to normal externally cured concrete mixes of all the grades considered for study. This improvement is due to the continuous hydration process due to which continuous availability of water resulting in lower pores and voids and strengthens the bond force between the aggregate and cement paste.

The incorporation of polyethylene-glycol to concrete reduces water evaporation,which leads to an increase in water retention capacity of the concrete eventually leading to improved compressive strength. This improvement in strength is due to incessant cement hydration is becauseof retained water presence and also due to the conversion of calcium hydroxide into calcium silicate hydrate (CSH) strengthening the interface aggregate-matrix transition zone which becomes less porous and more compact. The most likely explanation given by the past researchers is that the PEG 400 is affecting the bond between the cement paste and the aggregate paste which is usually surrounded by massive crystals of CH, having the nature of these crystals effects the strength of the cement paste-aggregate bond, which in turn influences the greater strength of the concrete. Past researchers reported that the addition of the PEG can make changes in the morphology of CH in cement pastes. This appears to enhance the nature of CSH gel, leading to better permeability characteristics.

The rebound index gives an idea about the hardness of concrete upto a certain depth and the internal cracks.It does not indicate heterogeneity along the cross section will not be indicated by rebound numbers. Measuring Ultra Sonic pulse velocity helps in assessing concrete density and modulus of elasticity. Combination of Ultra Sonic Pulse Velocity and Rebound hammer helped in assessing strength and quality It is seen the rebound number values and ¬ultrasonic pulse velocity increased due to refined pore structure and microstructure of hardened self-curing agent incorporated concrete making the concrete highly dense. Similar observation is noted in all the grades of self-curing agent treated concrete specimens. This considerable growth of compressive strength is due to the addition of hydration products which modifies the concrete pore structure by plugging the voids /or the pores within cement–sand matrix, as part of PEG's chemical activity.

7. Conclusions

The following conclusions can be noted through the results of study and experiments:

The use of self-curing agent (polyethylene glycol) in concrete mixes improves the strength also the properties of concretes under regime of which are due to a good water retention. This results in continuous cement hydration and minimum pores and voids.This helps in establishing stronger bond force between aggregate and cement paste. The optimum dosage of polyethylene glycol PEG 400 (expressed in percentage by weight of cement) for M20, M40 and high grade M60 grades self-cured concrete are 1%, 0.5% and 0.5% respectively.

There is a considerable increase in the compressive, split-tensile and flexural strength properties self-curing concrete mixes at all ages of curing when compared to normal externally cured concrete mixes.

It is hereby concluded that for all grades of self-curing agent incorporated concrete, rebound numbers obtained indicate the superior surface hardness than normal concrete and also the USPV measurements were greater than 4.5km/sec which denotes that all grades of self-curing agent induced concrete are classified as 'excellent' concretes in terms of strength and durability point of view due to improved pore structure which also effects durability and mechanical response through enhanced hydration and strengthening of inter facial transition zone whereas controlled concretes are classified from 'good' to 'excellent'.

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