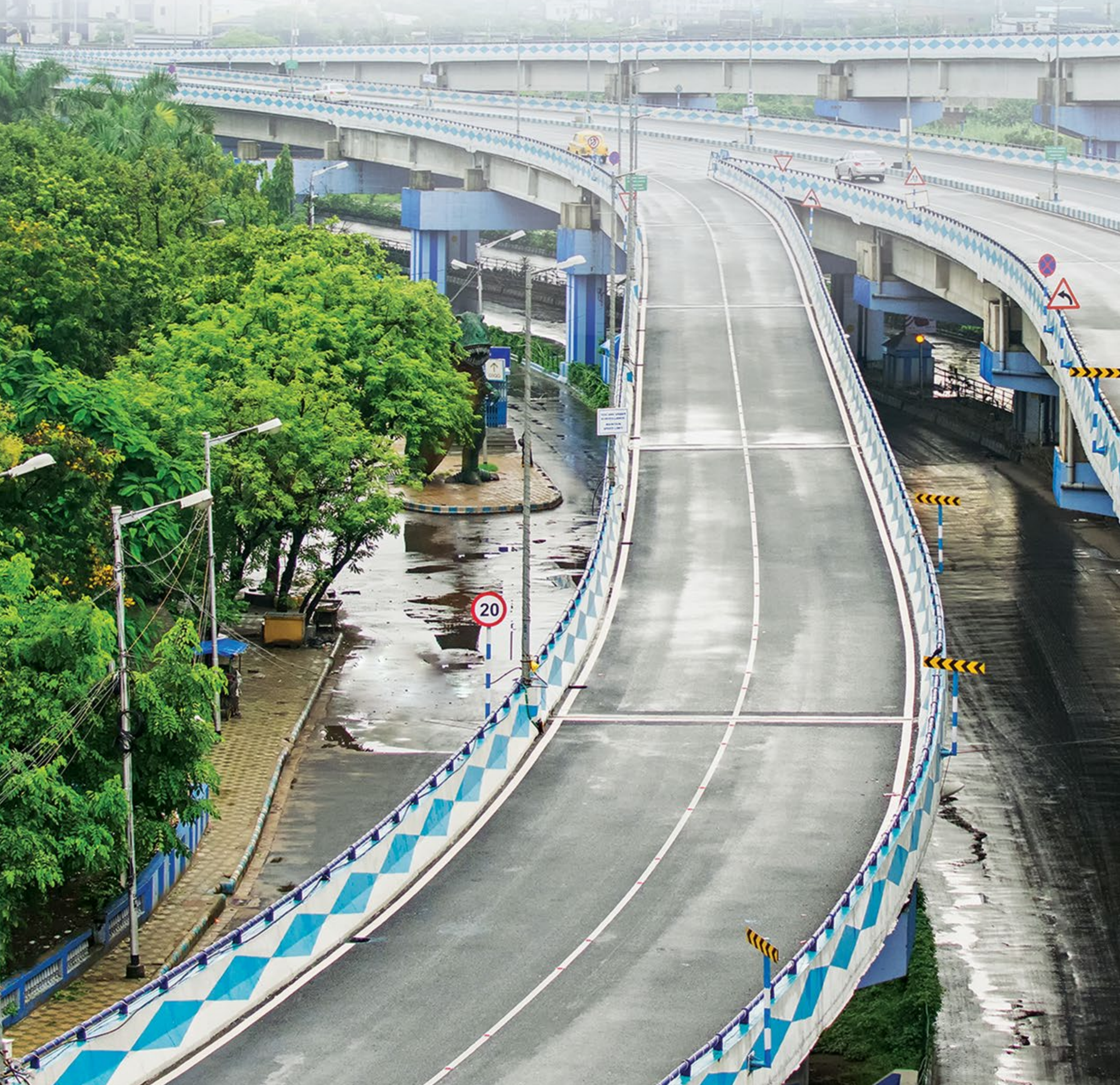
Global Cement and Concrete Association

India

BLENDED CEMENT

- GREEN, DURABLE & SUSTAINABLE

2022



EXECUTIVE SUMMARY

Amongst the eight core industries of India, cement industry plays a vital role in the growth and economic development of our country because of its strong linkage to other sectors such as infrastructure, construction, housing, transportation, coal, power, etc. The installed capacity of cement industry in India is 537 million tonnes with cement production of around 334.37 million tonnes in 2019–20, which comprises 144 integrated large cement plants, 107 grinding units, 62 mini cement plants and 5 clinkerisation units. Cement is considered to be responsible for about 7% of global anthropogenic CO_2 emissions. Despite having the highest potential to reduce these emissions in an economically and technically feasible manner, the blending of mineral additions with cement is still significantly below its potential. This document addresses some of the misapprehensions about the use of blended cements that affect its acceptance and presents a comparison of these cements with Ordinary Portland Cement.

Blended cements are formulated by blending of portland clinker with other finely ground materials such as pozzolana and granulated blast furnace slag. The partial replacement of clinker, which is not only the more expensive component of cement, but also the most resource, energy and emission intensive, with mineral additives improve the sustainability of the material. Most importantly, as explained in this document, the performance of cements can be improved through this replacement, making blended cements the most attractive means to achieve sustainable infrastructure development.

The availability of fly-ash (from thermal power plants), blast furnace slag (from steel plants), use of advanced technology in the manufacturing of cement and simultaneous increase in market demand has increased the production of blended cement in the recent years. In India, the production of OPC is continuously declining, with simultaneous increase in production of blended cements like PPC, PSC, and Composite Cement based on granulated blast furnace slag and fly ash. Other cement formulations such as Portland limestone cement and limestone calcined clay cement are also at different stages of development in India. At present, blended cements have greater share (73%) in comparison to Ordinary Portland Cement (27%) of the total cement production. Blended cements provide the means to reduce the clinker factor even further in the near future, without a compromise on economy and safety.

TECHNICAL ADVANTAGES OF BLENDED CEMENTS

The fly ash – slag based composite cement is a relatively newly standardized type of cement and its specifications have only been formulated by the Bureau of Indian Standards in 2015. Its commercial production has already started in the country. The composite cement (conforming to IS: 16415–2015) can be produced either by inter-grinding of portland cement clinker (conforming to IS: 16353–2015), granulated slag (conforming to IS: 12089–1987) and fly ash (conforming to IS: 3812 (I) 2013) with the addition of natural/chemical gypsum or by an intimate and uniform blending of ordinary portland cement (conforming to IS: 269–2015), finely ground granulated slag and fly ash with the addition of ground gypsum. The composite cements are manufactured using 35–65% portland cement clinker/ ordinary portland cement along with 15–35% fly ash and 20–50% granulated blast furnace slag together as the blending component.

In this document, the advantages of different blended cements over OPC are discussed based on hydration, microstructure and permeability, rheology and workability, strength development, shrinkage (chemical, autogenous, drying etc.) and cracks, leaching, alkali aggregate reactivity, sulphate attack, reinforcement corrosion, long-term durability of construction and usage in preparation of high strength concrete.

The risk of thermal cracking is reduced in blended cements, compared to OPC due to the lower rate of heat evolution and the total amount of heat liberated during hydration. The temperature has a considerable effect on the total amount of heat evolution for a particular cement. The dormant period, the period during which the concrete can be safely transported, placed, finished, etc., is prolonged in blended cements due to the presence of the mineral additives such as fly ash and slag allowing easier working on the site and lesser wastage of the cement. The lower amount and rate of the heat of hydration for blended cement also makes them suitable for use in mass concrete structures such as dams and spillways.

In general, concrete made with cement blended with Supplementary Cementing Materials (SCMs), or where ordinary portland cement is partly replaced with SCMs, is more durable than concrete made with ordinary portland cement at the same water-to-binder ratio. The main reason is the formation of denser microstructure both due to improved particle packing initially and more Calcium Silicate Hydrates (CSH or CASH) formed from the conversion of calcium hydroxide (CH) due to what is known as the pozzolanic reaction. Improvements in the Interfacial Transition Zone (ITZ), which is usually regarded as a major feature governing the permeability of concrete, are seen to improve the durability and strength of concrete. The fine particles of the SCMs and the formation of the C-S-H gel from the pozzolanic reaction play an important role in the improvement of the ITZ.

Most research shows an improvement in the rheological properties of fresh concrete with the incorporation of SCMs. Since the workability of a freshly prepared concrete mix depends upon several factors such as the cement type, its fineness, a direct comparison of the ease with which various cements can be worked is difficult to compare. Even though some blended cements, due to their higher fineness can have a higher water demand than OPC, the presence of fine particles reduces the tendency to segregate and improves the flow of the concrete. The rounded particles of fly ash, even after distortion from grinding in the blended cements, offer a ball-bearing effect, improving flow. High-performance concrete mixes, such as self-compacting concretes, are difficult to produce without the use of SCMs.
Strength gain in blended cement is lower at early ages

but higher at later ages. With sufficient curing, the large potential of strength of concretes produced using blended cements can be tapped.

The shrinkage strains are comparable at early ages of the drying period for concrete made out of all types of cement blends. However, in the case of binary blends, use of PPC and PSC reduces the drying shrinkage of concrete in comparison to concrete made with OPC. Furthermore, in the case of ternary blends, shrinkage reduces with the higher replacement level of fly ash and slag in comparison to concrete made with OPC. This reduces the risk of cracking and improves the durability of structures.

The consumption of calcium hydroxide and the production of calcium silicate hydrate in the pozzolanic reaction refine the pore structure of cement matrix, thus enhancing the resistance of the cement-based materials against the transport of species from and into the concrete.

The use of SCMs/mineral admixture/blended cements in concrete significantly helps in mitigating the expansion due to alkali silica reaction (ASR), due to the reduction in the availability of alkalis in the pore solution and the refinement of the pore structure. Not only does this reduce maintenance costs of infrastructure such as dams and bridges, but also allows the consumption of local aggregates that may contain deleterious materials. The reduced expansion in SCM-blended systems reduces the risk of expansion and cracking.

This pozzolanic reaction also has the following beneficial impacts on sulphate attack:

a) The consumption of portlandite reduces the formation of gypsum, reducing the expansion and scaling of concrete

b) The replacement of part of the cement by a pozzolanic material dilutes the C3A content and hence all the aluminate bearing phases will accordingly be reduced;

c) The formation of secondary C–S–H also results in the densification of the hardened cement paste since it is deposited in the pores thereby making blended cements impermeable and, therefore, the sulphate ions cannot easily penetrate through the concrete matrix, as in the case of plain Portland cements.

Severe deterioration is however observed in all cements in the case of the rare exposure to high concentrations of magnesium sulphate, due to the reaction with portlandite to form gypsum and brucite (magnesium hydroxide). In the absence of portlandite, the C-S-H phases are attacked. This can lead to a disintegration of the hardened cement paste.

Chloride Induced Corrosion:

Concrete made with blended cements has very low chloride ion permeability or diffusivity as compared to OPC concrete, although it has a low chloride threshold value. The initiation period of concrete made with SCM will be higher in comparison to OPC concrete. The propagation period of concrete structure made with SCM significantly increases due to a lower corrosion rate in comparison to concrete made with OPC. This increases the service life of structures and reduces repair and maintenance costs.

Carbonation Induced Corrosion:

Due to the lower CO_2 emitted during the production process, blended cements also have a lower capacity to reabsorb CO_2. For this reason, concretes made with blended and composite cementitious material show a lower resistance against carbonation as compared to OPC. The carbonation depth of concrete made with blended cement is found higher in comparison to OPC at the same exposure period. As a result, the corrosion initiation period of concrete made with blended cements is likely to get reduced. Experience with fly ash based cements has shown that the long-term performance of blended cements is satisfactory as long as good construction practices are followed. While carbonation depths are increased in blended cement concretes, the resultant impact on corrosion propagation is still a subject of much research.

Performance of concrete or mortar is governed by mechanical and durability parameters. Both properties of concrete depend upon microstructural, chemical and physical characteristics. The chemical characteristics of concrete such as pH, reserve alkalinity and hydration products and physical characteristics such as permeability, shrinkage, etc. govern the concrete durability. Long term durability of concrete structure is directly related with the resistance of concrete against aggressive agencies like sulphate, chloride, carbonation, the heat of hydration, Alkali Silica Reaction (ASR), leaching etc. The effect of blended cement on mechanical and durability parameters have been tabulated on the next page.

Table: Performance of Blended cement concrete as compared to OPC concrete

S. No.	Parameter	Performance of Cement			
		OPC	PPC	PSC	CC
1	Heat of Hydration	High	Lesser	Lesser	Lower
2	Permeability	High	Lesser	Lesser	Lesser
3	Long term Strength	Normal	Higher	Higher	Higher
4	Shrinkage	High	Lesser	Lesser	Lesser
5	Alkali Aggregate Reaction	Less Resistance	Higher Resistance	Higher Resistance	Higher Resistance
6	Sulphate attack	Less Resistance	Higher Resistance	Significantly Higher Resistance	Higher Resistance
7.a	Chloride Induced Corrosion	Less Resistance	Higher Resistance	Higher Resistance	Higher Resistance
7.b	Carbonation Induced Corrosion **	High Resistance	Lower, but acceptable with good construction practices		

*In case of PPC, workability is enhanced when fly ash is mixed separately with OPC. But in case of intergrinding fly ash, water demand increases.

**The conclusion is drawn on the basis of the carbonation depth of concrete made with and without blended cements. However, the effect of CO_2 ingress on corrosion rate still requires comprehensive study in the propagation phase.

From the analysis of results of the above parameters, the performance of Blended Cement was observed better than OPC concretes excluding resistance against carbonation. So, concretes made with PPC, PSC and CC have a longer service life as compared to OPC concrete in aggressive environment.

Commercially available PSC in India has 50–60 % slag content whereas commercially available PPC in India has 30–35 % fly ash content. They are used for general purpose construction for a grade of concrete up to M50. For higher grade of concrete, customized PPC and PSC should be used with a lower % of fly ash and slag respectively. These blended cements thereafter may be used with the appropriate proportion of silica fume for the production of high strength concrete.

Indian standards and codes of practices recommend PPC and PSC in Plain, Reinforced and Prestressed Concrete construction and there are no constraints in their usage. Various circulars and specifications are given by CPWD, IRC, BIS and Ministry of railways. In the year 2009, the CPWD permitted the use of PPC vide their circular No. CDO/SE (RR)/Fly Ash (Main)/102 dated 09 April 2009 for concrete grade of M25 and above in RCC. Similarly, the use of PPC for prestressed concrete was earlier not recommended in different standards / specifications due to apprehension of late strength development, apprehension of low resistance towards carbonation induced corrosion of steel and lack of data on other critical properties of prestressed concrete like creep, shrinkage and fatigue. However, based on extensive research done at several R&D institutes of the country, Bureau of Indian Standard permitted the use of PPC in prestressed concrete by revising IS: 1343 in 2012.

The use of PPC and PSC is permitted by national and international Standards / Specifications including most government bodies. The use of Portland Pozzolana Cement conforming to requirements of IS: 1489 is already permitted by Ministry of Railways, Railway Board, Government of India, in substructures of bridges. As per "Guidelines for the Use of High-Performance Concrete Bridges" issued by the Ministry of Railways, Railway Board, Government of India, fly ash conforming to grade I of IS: 3812-2003 can be used where proportion should not be less than 20 percent and nor should exceed 35 percent by mass of cement. IRC: 112-2011 specifications "Unified code of Practice for Concrete Road Bridges provision for the use of blended cement" also permits the use of PPC in prestressed concrete structures. Internationally, PPC is permitted for use in prestressed concrete structures by Prestressed Concrete Institute (PCI) Manual, AASTHO specification, ASTM C-935 etc.

ENVIRONMENTAL ADVANTAGES OF BLENDED CEMENTS

MATERIAL COMPOSITION

OPC
95% Clinker
5% Gypsum

PPC
31% Fly Ash, 64% Clinker, 5% Gypsum

PSC
57% Slag, 38% Clinker, 5% Gypsum

CC
25% Granulated Slag, 45% Clinker
25 % Fly Ash, 5% Gypsum

REDUCTION IN CO_2 FOOTPRINT

OPC	PPC	PSC	CC
740	511	304	348

REDUCED ENERGY CONSUMPTION

Thermal energy in Kcal/Tonne

OPC	PPC	PSC	CC
724	495	305	343

Electrical energy in Kwh/Tonne

OPC	PPC	PSC	CC
87	64	59	57

INCREASED PRODUCTION CAPACITY

REDUCED LIMESTONE REQUIREMENT FOR PRODUCTION OF BLENDED CEMENT

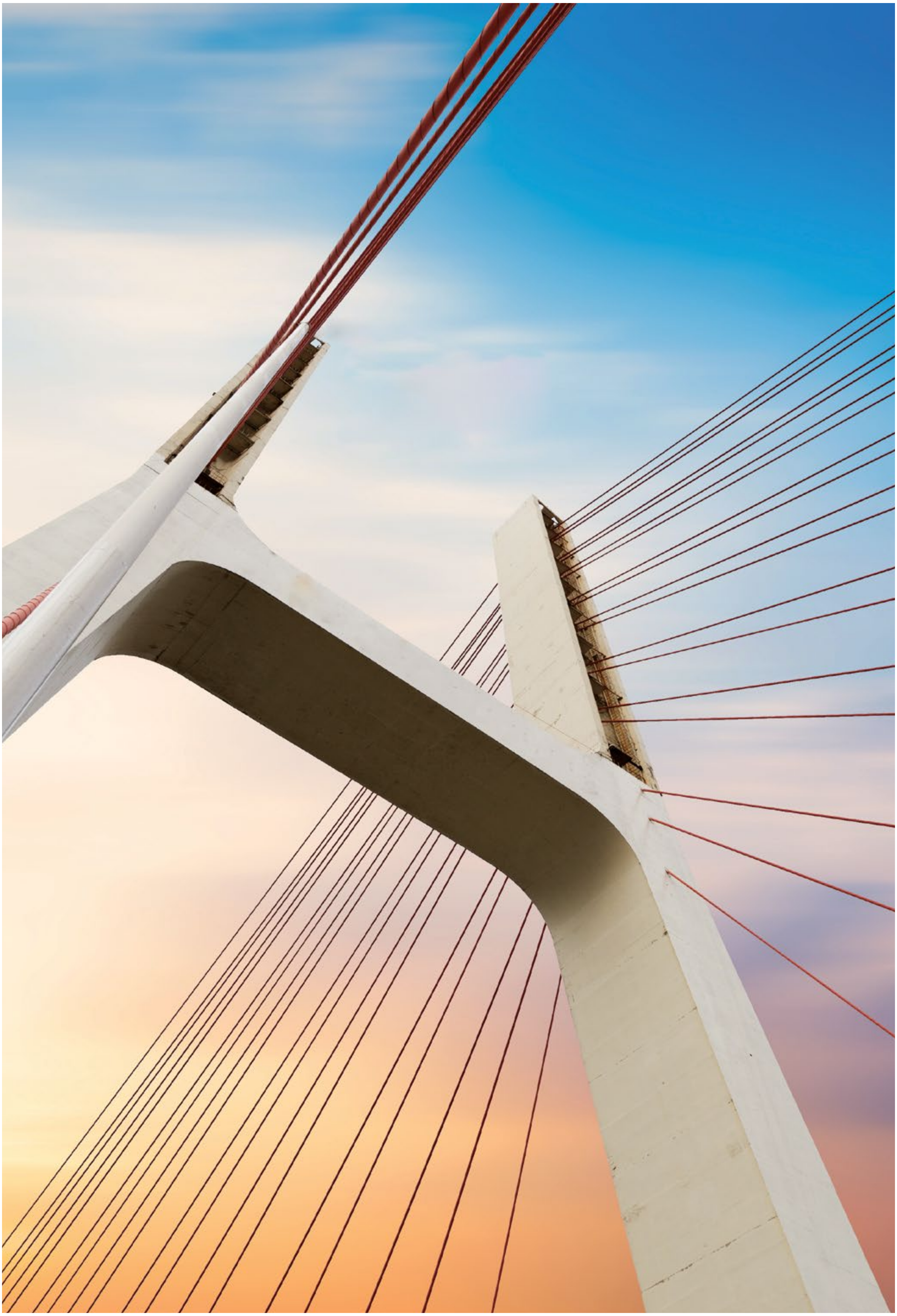
In India, there are only three blended cements approved by BIS, namely, PPC, PSC and Composite Cement. The other blended cements namely Portland Composite Cement based on both fly ash and limestone (PCC), Portland Limestone Cement (PLC), Portland Dolomitic Limestone Cement (PDC), Limestone Calcined Clay Cement (LC3) and multicomponent blended cements are at different stages of development in India. However, this report focuses on the performance of OPC, PPC and PSC mainly and upto some extent on composite cement for which the Indian standard is available.

The use of blended cements is widely internationally accepted and standardized. The European code 197–1–2011 gives specification of 27 distinct common cement products and their constituents. The code provides the proportions in which the constituents are to be combined to produce these distinct products in a range of six strength classes. The 27 common cements are grouped into five main cement types namely CEM-I, CEM-II, CEM-III, CEM-IV and CEM-V. Except for CEM-I which covers OPC rest for all the other cement groups i.e. CEM-II, CEM-III, CEM-IV and CEM-V consist of only blended cement. The blended cement covered in these cement groups CEM-II, CEM-III, CEM- IV and CEM-V are Portland slag cement, Portland fly ash cement, Portland silica fume cement, Portland limestone cement, composite cement, Portland burnt shale cement, blast furnace cement, pozzolanic cement. The latest European code 197–5–2021 also allows the production of cements with much lower clinker contents with various SCMs including fly ash, slag, calcined clay, limestone, etc.

The Canadian standard, A3001–13–2017, comprises 26 types of standardized cements. Out of which 20 are blended cements, which include Portland limestone cement, Portland slag cement, pozzolana cement and ternary/quaternary blended cements. The standard allows the use of upto 50% fly ash (both siliceous and calcareous) in pozzolana cement and up to 60% fly ash in ternary/quaternary blended cements.

In comparison to the Indian standards, the European code covers a greater number of blended cements and it is also noted that cement group CEM-IV-B, Pozzolana cements, allows 36–55% of natural pozzolana and fly ash along with clinker and CEM-V-B, composite cements, allows the 31–49% of natural pozzolana and calcareous fly ash along with slag and clinker in it. On the other hand, in the Indian standards, both the Portland pozzolana cement and composite cement allow not more than 35% of fly ash usage. Also, there is a high need for the commercialization of new blended cements after getting due approval from BIS.

It can be seen in this report that blended cements demonstrate superior performance when compared to OPC. Not only do the blended cements offer a more sustainable solution for the CO_2 intensive industry, they also reduce the risk of cracking, allow easier construction, increase long-term strength and prolong the durability of structures in a wide range of environments from dams in the mountains to bridges on the open seas. Blended cements are a better replacement for Ordinary Portland Cement. In addition, both PPC and PSC are ideally suitable for mass concrete works, constructions in aggressive conditions such as marine, coastal and sub-coastal environments and chemically aggressive conditions. Even under normal conditions, they impart long term strength and improved durability. Considering the environmental and sustainability benefits of blended cements, state and central governments can incentivize these cements over OPC.



GCCA INDIA MEMBER COMPANIES

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- Ambuja Cement – Giant Compressive Strength
- MP Birla Group – Birla Corporation Limited
- Dalmia Bharat
- HeidelbergCement
- JK Cement Ltd.
- JSW Cement
- Nuvoco – Shaping a new world
- Orient Cement – CK Birla Group
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