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Evaluation of Fresh State and Mechanical Properties of Cementitious Grouts

Yogita Gaude1[1*], Dr. K. G. Guptha[1], Er. T. Mohan[2]

[1]Department of Civil Engineering, Goa College of Engineering, Goa, India
yogitagaude123@gmail.com, ORCID: 0000-0002-8054-6972,
ORCID: 0000-0002-1269-8501
[2]AGM QA/QC at Dilip Buildcon Ltd., Goa, India
ORCID: 0000-0003-4626-1196

Abstract: Many construction activities, such as prestressed cable ducts (internal or external) for structural elements, masonry and RCC structure repair and reconstruction, shoring and soil stabilization, geotechnical applications, and so on, use cement grouting. These grouts comprise basic elements such as cement, sand if used, water and, possibly, admixture(s) along with non-shrink chemical admixtures. They exhibit higher compressive strength compared to other materials. Varying the mix proportions and dosages of the different additives used can easily change the rheology and characteristic properties of the grout. Grouting of cable ducts of prestressed structures to fill in the voids or gaps between the ducts and prestressing strands is a large-scale application of cement grouts. Damages such as corrosion and rupture of prestressing tendons/strands due to insufficient grouting and/or chloride attacks from airborne salts, use of de-icing salts, or use of sea sand in the concrete can cause these structures to deteriorate in strength and durability. In such situations, there is a possibility that this sea water or de-icing salt may penetrate into the ducts, thus corroding the prestressing strands/cables. The entire structure's tensile load carrying capacity is mainly dependent upon the tensile stress carrying capacity of cables/strands. As a result, the alkaline/passive layer, i.e. grout, must be thoroughly mixed and injected into the ducts ensuring a pressure of 0.5 Mpa. However, a minimum pressure of 0.3 MPa is required. As a safety measure, the maximum grouting pressure is limited to 1 Mpa in order for it to achieve the desired properties after hardening. Bleeding occurs when using pure cement grout, reducing the w/c ratio but increasing strength. As a result, admixtures such as Cebex 100, Cebex 200, and Cebex EN or equivalent are added to the pure cement grout to improve its rheological properties such as bleeding, compressive strength, and durability properties such as shrinkage and permeability, and their properties are investigated. Experimental investigation was carried out by conducting standard cube tests at 3 days, 7 days, 14 days, and 28 days, respectively as specified by the Indian standard codes. The addition of admixtures to cementitious grouts results in a marginal reduction in compressive strength whereas reduction in density (at 14 days) is negligible. The ability to mitigate shrinkage is the main reason for using these admixtures. Cebex EN grout is the only manageable grout when it comes to mix temperature, bleeding, density, and compressive strength. As a result, it is suggested for grouting. Understanding the performance of cementitious grouts based on dosage and other additives at a major River Bridge Project in Goa is the goal of this research.

Keywords: Cebex EN, Cebex 100, Cebex 200, Cementitious grouts, Compressive strength, Non-shrink chemical admixtures, Shrinkage.

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1. Introduction

Cement grout is a mix/blend of cement, water, sand (if applicable), and likely admixture(s) in the appropriate mix proportions and dosages, with or without non-shrink additives [1]. These grouts are used in a variety of civil engineering and building applications, including crack sealing, protective coatings, soil anchoring, grouting of prestressed cable ducts, masonry and concrete foundations, repairs and renovation, and so on [1], [7]. This is particularly because of the advancements that occurred in recent years through the usage of cementitious materials and chemical admixtures.

* *Corresponding author; yogitagaude123@gmail.com*

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Cement-based grouting is adopted for prestressed bridges/structural components especially for the grouting of cable/tendon ducts, girders, piers, bearings, etc. as a large quantity of work is concerned and calls for a lot of precautions to be taken. The quality of the duct grouting is directly proportional to the reliability of the structure. This is because these tendons/cable strands are prone to corrosion due to inadequate grouting, poorly filled ducts, chloride attacks from airborne salts, presence of de-icing salts, or use of beach/sea sand in the concrete, which causes tensile strength of cables to deteriorate (oxidize) due to contact with atmospheric air, presenting a long-term disaster [6]. As a result, the grout pumped into the prestressing duct acts as a protective sheath, preventing corrosion of the pre-stressing tendons/ strands [2]. Various filler elements including fly ash (FA), silica fume, ground granulated blast furnace slag (GGBS), micro-cement, and many others have been incorporated in the mix in the past to enhance the fresh state behavior and mechanical resistance of grouts such as flowability, bleeding, time required for setting, and durability.

Because of their consistency and increased compressive strength, cement grouts are preferred. The water to cement ratio (W/C) of a grout mix is inversely proportional to its compressive strength. As a result, superplasticizers are needed to achieve the desired flowability in grouts with lower W/C ratios. Shrinkage, in addition to compressive strength, is one of the most significant factors influencing the grout's durability. As a result, some chemical additives with non-shrink properties must be incorporated into the grout mix to mitigate the effects of shrinkage and to ensure expansive properties to the grout. The use of pure cement grout results in bleeding which further leads to lowering of the w/c ratio but enhancing the compressive strength. As a result, certain admixtures such as Cebex 100, Cebex 200, and Cebex EN will be added to enhance its rheological and mechanical properties such as bleeding, shrinkage, and compressive strength, and their requisite properties will be determined. This study focuses on understanding the working principle and performance of cementitious grouts based on dosage and other additives at a major River Bridge Project in Goa. The research study aims at recommending mix proportions and dosages of additives to be used for grouting prestressed cable ducts at Zuari River Project-Goa. This topic demonstrates the comparison of test results of various trials conducted in the laboratory and on-site.

2. Literature Review

Various researchers contributed immensely to cement grouts through their research studies, and their research work was documented and reported, including basic findings and methodology.

Kim et al. (2016) [3], investigated the characteristic features of steel fiber-reinforced grout mix (SFRG) made up of ground granulated blast furnace slag or blast furnace slab (GGBS) in both its fresh as well as hardened states. They examined the influence of various cement types and GGBS volume content on the characteristics of SFRGs. The addition of steel fibres reduced the flow, bleeding, and setting time of SFRGs, while the use of GGBS as a 40% replacement of the cement by weight ratio increased the flow and setting time. The addition of steel fibres, also resulted in an increase in chloride penetration resistance under severe marine environmental conditions, as well as a marked increase in flexural strength and improvement in crack resistance, but it also resulted in a decrease in flowability, bleeding, and setting time.

Li et.al. (2017) [4], conducted a research study to evaluate rheological properties, fresh states properties, and also mechanical properties of some microfine cement grouts (MC) (of which three are Portland-based and remaining three comprises of slag-blended) and also two of them comprises ordinary Portland cement-based grouts with or without superplasticizer (SP). It was deduced that rheology and mechanical behaviour of microfine cement grouts were altered by W/C ratio, fineness and type of cement particles in the mix, and the addition of superplasticiser, etc. As the W/C ratios increased, there was a reduction in rheological properties however, it caused other effects such as excessive bleeding, prolonged setting time, and reduction in mechanical properties demanding the use of lower W/C ratios (in the range of 1.0–1.5) to achieve higher strengths of grouted rocks or grouted sands. Whereas, all these properties were improved with an increase in the fineness of cement. Portland-based MC grouts showed higher compressive strength, sand consolidation strength and elasticity modulus as compared to that of MC grouts comprising of slag blended with low W/C ratios. As the fineness of the MC particles increases, it helps in proper filling of sand voids and increasing the cementing ability between the soil and the grout.

Yoo et al. (2017) [5], investigated the use of shrinkage-reducing admixtures (SRA) to minimize the cracking tendency of post-tensioning high-performance grout (HG). They produced the HG mixture to be fluid with minimal bleeding and settling. Also, results were compared with Ordinary grout (OG) mixture. Both the mixes were found to be flowable to the same extent. Incorporation of SRA to the HG mixture led to increased compressive and tensile strength after 28 days, lower shrinkage strain and maximum internal temperature due to heat of hydration, and delayed shrinkage cracking. At all ages, HG samples assisted in the complete filling of ducts and exhibited the highest free shrinkage strain. The OG mixture, on the other hand, developed the smallest shrinkage strain, provided sufficient shrinkage cracking resistance, but resulted in insufficiently filled ducts, exposing prestressing strands to atmospheric moisture. Based on the findings, it was determined that both the HG and OG mixtures met the flowability requirements. In OG

samples, however, there was more bleeding and settling than in HG samples. As a result, it was suggested that the HG mixture with 2% SRA be used, as it is the most suitable for post-tensioned grouting applications.
Vasumithran et al. (2020) [7], investigated the impact of fillers such as fine sand and fly ash on cement grouts, as well as the flowability and mechanical properties of these grouts. Mixes containing fillers had lower water-cement ratios and were thus non-workable. Therefore, a polycarboxylate ether-based superplasticizer was introduced into the mix. In all of the grouts, 10% of the cement mass was replaced by silica fume, while in some of the mixes, 50% of the cement mass was replaced by fillers. An increase in the water-cement ratio resulted in a variety of issues, including excessive bleeding, instability of the grout, longer setting times, and poor mechanical strength. The presence of silica fume in the mixes rendered the mixes less workable at low water-cement ratios but showed increased strength compared to other mix types. As opposed to cement grouts made solely of silica fume, the use of fine sand and fly ash in the grout resulted in lower initial strengths. Grouts made up of filler materials like fine sand, on the other hand, showed increased shrinkage and water absorption. Higher compressive, flexural, and bond strengths were observed when these fillers were not incorporated into the grout mix. As a result, fine fillers such as fine sand and fly ash were found to be a suitable replacement for cement in terms of durability.

3. Methodology

3.1 Materials

In this study, a variety of materials were used to prepare grouts, including:

A. Cement

Grouting is commonly done with ordinary Portland Cement (OPC). Chemical impurities such as chlorides and sulphates, as well as lumps, should be avoided in the cement. It must have the requisite setting time and a maximum temperature of 40 degrees Celsius. Cement for grouting should conform to IS 269:1989 or 1489 (Part 1):1991 and 1489 (Part 2):1991. For conducting experiments, Ultratech cement-53 grade was employed as presented in Figure 1.

B. Water

The grout mix should be prepared with potable water that meets IS 456:2000 standards and is free of impurities. The use of seawater must be avoided at all costs. The temperature of the water to be used should not exceed 5 degrees Celsius. Water from the Ready-Mix Concrete (RMC) plant was adopted in the grouting mix to conduct experiments in the laboratory.

C. Admixtures

Chemical admixtures are added to the grout mix to enhance their rheological properties such as flowability of the grout, prevent entrainment of air, improve its mechanical and durability properties such as shrinkage, permeability etc. The additives used in the grout mix should be free of chlorides, nitrates, sulphates, or any other impurities that could cause the prestressing steel or grout to deteriorate.

The following is a list of the different additives used in this study. Figure 1 depicts the various materials used in this study.

a) Cebex 100 (Fosroc Chemical)

When positive expansion and a lower w/c ratio are desired, this admixture is used in site-batched cementitious grouts. It aids in the reduction of natural settlement and grout plastic shrinkage, maintaining stability and cohesion.

b) Cebex 200 (Fosroc Chemical)

Cebex 200 is a positive expansion type additive that is added to the cement grouts to reduce the water/ cement ratio.

c) Cebex EN (Fosroc Chemical)

Cebex EN admixture imparts expansive properties to the grout. Whenever a lower w/c ratio is desired, this additive is to be used. It comes in the form of a powdered mixture with plasticizing and hydrogen-free expansion properties. It provides higher strength and improves the durability of the mix.

(a) Ultratech Cement 53 Grade (b) Water

(c) Foscroc Cebex 100 (d) Fosroc Cebex 200 (e) Fosroc Cebex EN

Figure 1. Various materials used in the preparartion of grout mix

3.2 Grouting Equipments

A typical method of grouting used on-site during prestressed bridge construction is pressure grouting, which involves injecting grout material into the voids or gaps between the ducts and prestressing cables/strands using grouting equipment. Figure 2 and Figure 3 depicts a Twin drum grouting mixer with an additional agitator (which uses the pneumatic pressure principle) and a Single drum grouting mixer (which uses a screw conveyor to push the grout forward) respectively.

Figure 2. Twin drum grouting mixer with additional agitator- Grouting equipment

Figure 3. Single drum grouting mixer- Grouting equipment

3.3 Grouting Process

Figure 4 illustrates the flow diagram of the grouting procedure implemented on-site. There are three main steps to the field grouting process.

i. Mixing the contents of the grout according to the proposed mix design
ii. Keeping the desired level of pressure
iii. Pressure relief achieved by taking the necessary safety precautions

The contents of the proposed mix, namely cement and water are thoroughly mixed with the additives of known dosages employing a grout mixing device. The blending process is to be carried out for about 2-3 minutes which needs continuous agitation till the grout mix is pumped. To avoid choking, the grout has to pass through a grout strainer after mixing. The grout injection process is then started ensuring a pressure of 0.5 MPa. However, a minimum pressure of 0.3 MPa is required. As a safety measure, the maximum grouting pressure is limited to 1 MPa. Once the free movement of the grout is observed at the other end and the pumping point, the grout injection process shall be stopped. To ensure complete protection to the tendons or the bundled strands, the ducts must be completely filled with corrosion-inhibiting grout under pressure leaving no voids. This is presented in Figure 5.

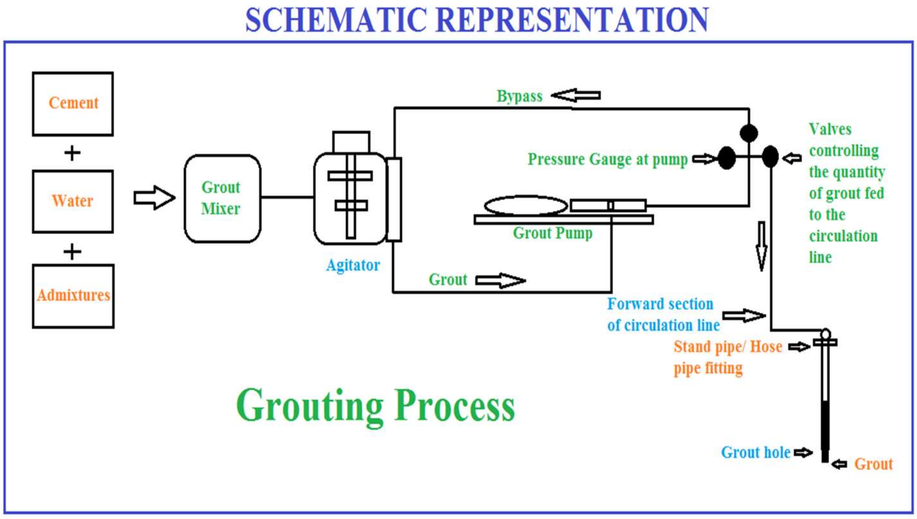


Figure 4. Grouting Process- A schematic representation

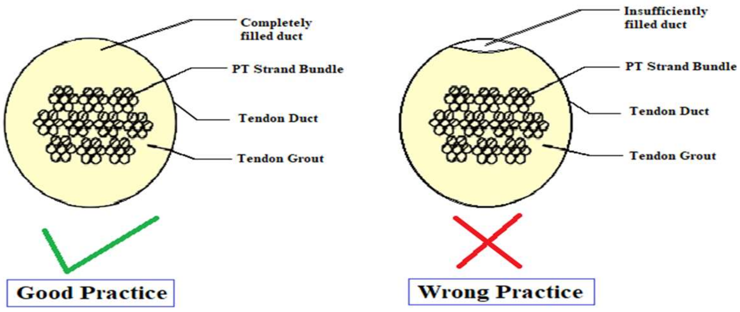


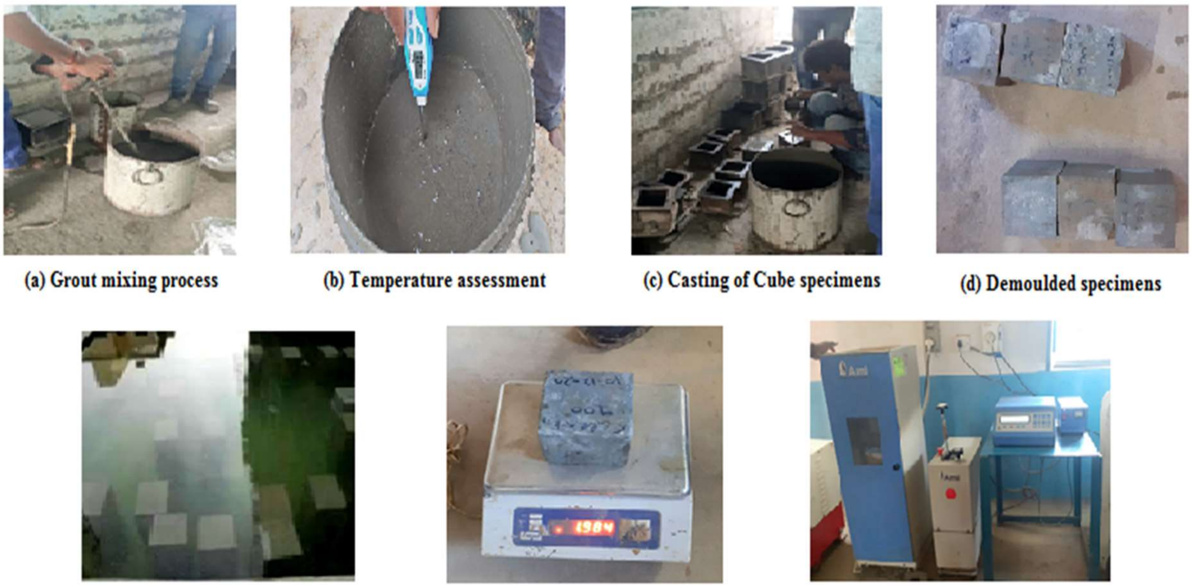
Figure 5. Do's and Don'ts for grouting- A comparison

3.4 Laboratory Experiments

Experiments were conducted within the laboratory to get the mechanical properties of grout like compressive strength. During this work, cubes were cast of 100mm X 100mm X 100mm each using grout mix which were then demoulded after 24 hours and left to cure in normal water. Cubes were then tested at 3 days, 7 days, 14 days, and 28 days, respectively for compressive strength. Figure 6 depicts a variety of laboratory tests, including temperature assessment of grout mix, grout mixing process, casting of cube specimens, normal water curing, and compression test. The mix design details of various trials conducted in the laboratory are presented in Table 1.

Table 1. Mix Design Trials

Trial specification	w/c ratio	Dosage of admixture
Pure OPC grout	0.4	-------
Grout with Cebex 100	0.4	0.45% by weight of Cement
Grout with Cebex 200	0.4	0.45% by weight of Cement
Grout with Cebex EN	0.4	0.45% by weight of Cement



(a) Grout mixing process (b) Temperature assessment (c) Casting of Cube specimens (d) Demoulded specimens

(e) Normal Water Curing (f) Weighing of specimens (g) Compression test

Figure 6. Experiments conducted in the laboratory on the grout mix

3.5 Onsite Measurements

Figure 7 depicts the various on-site experiments such as temperature measurements of cement, water and grout mix, flow test/ mass cone viscosity test, bleeding test etc. Once the grout mix is ready, the temperature must be measured at the grout inlet as well as at the grout outlet once the grouting is complete. It is observed that the temperature of the grout at the outlet rises as it flows through the ducts because of pressure and friction between the prestressing steel and ducts and as well as the hydration of cement. This increase in temperature is in the range of 0.05-0.1˚C increment per metre length of span including the length of supply grout pipe. It is also affected by weather conditions such as rain, frost, and winter, as well as early morning hours. Temperature increments would be lower during these times. Flow test or mass cone viscosity test is also conducted using Marsh cone equipment as per ASTM C949. The efflux time should be between 20 to 30 seconds. A bleeding test was also carried out on the grout mix which was kept at rest for three hours. The bleed percentage is limited to 0.3.

(i) Cement (ii) Water (iii) Grout mix

(a) Temperature assessment on-site

(b) Flow test/ Mass cone viscosity test (c) Bleeding test

Figure 7. Experiments conducted on-site on the grout mix

4. Results & Discussions

The temperature measurement results of source materials and grout mix were noted for various laboratory and on-site grouting batches. The temperature of cement, water and grout mix at inlet and grout mix at the outlet should be less than 40 ˚C, 5 ˚C, 16 ˚C and 25 ˚C respectively. The bleeding, density and compression test results are presented in Table 2, Table 3 and Table 4 respectively.

From Table II, it can be deduced that high bleed allows water to escape, resulting in voids that can result in losing contact between the prestressing steel and the surrounding structural concrete, excessive segregation and sedimentation of the grout material. The hydration reaction is also incomplete since water escapes by bleeding. Cebex EN shows negligible bleeding. Pure OPC grout, on the other hand, shows the highest amount of bleeding. Bleeding is moderate for grouts with Cebex 100 and Cebex 200.

Table 2. Bleeding results

Trial mix details	Maximum Bleed content (in %)
Pure OPC grout	2
Grout with Cebex 100	1
Grout with Cebex 200	1
Grout with Cebex EN	0.1

Table 3. Density Results

Trial mix details	Average 3 days density (KN/m^3)	Average 7 days density (KN/m^3)	Average 14 days density (KN/m^3)	Average 28 days density (KN/m^3)
Pure OPC grout	2073	2113	2128	2073
Grout with Cebex 100	2040	2049	2032	2053
Grout with Cebex 200	1992	2022	1999	2039
Grout with Cebex EN	1968	2035	2024	2052

Table 4. Compressive Strength results

Trial mix details	Average 3 days strength (N/mm^2)	Average 7 days strength (N/mm^2)	Average 14 days strength (N/mm^2)	Average 28 days strength (N/mm^2)
Pure OPC grout	32.15	35.44	54.27	56.47
Grout with Cebex 100	26.20	28.40	36.93	38.73
Grout with Cebex 200	20.83	29.78	37.43	41.56
Grout with Cebex EN	17.87	33.57	42.62	46.75

Figure 8 depicts the temperature of the mix as a function of time for the trials conducted. For pure OPC grout, the temperature rises sharply for 60 minutes, which then again falls up to 150 minutes before attempting to stabilize. 0-60 minutes can be termed as a high-temperature zone in which the temperature rises rapidly while 60-120 minutes is a time where the temperature attempts to return to normal. Pure OPC grout has lower temperatures than grouts with admixtures since it bleeds, allowing water to escape resulting in less reaction. Cebex EN, on the other hand, has a steady temperature rise that lasts up to 60 minutes. It tries to stabilize after 60 minutes. As a result, Cebex EN maintains the temperature and heat of hydration in the grout. Therefore, Cebex EN is a stable grout in terms of mix temperature. Whereas, grouts with Cebex 100 and Cebex 200 takes a long time to stabilize.

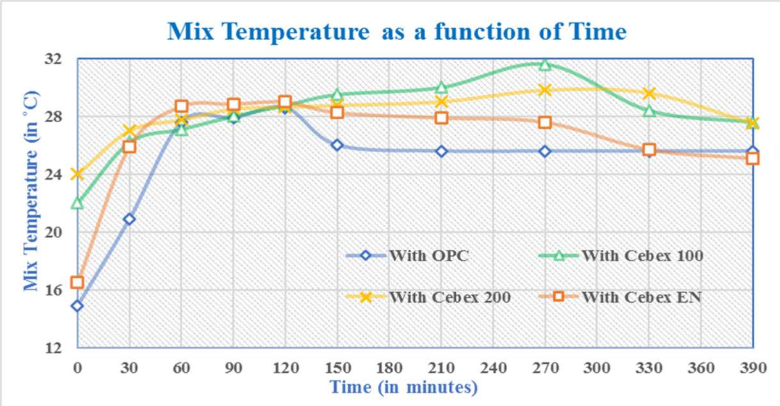
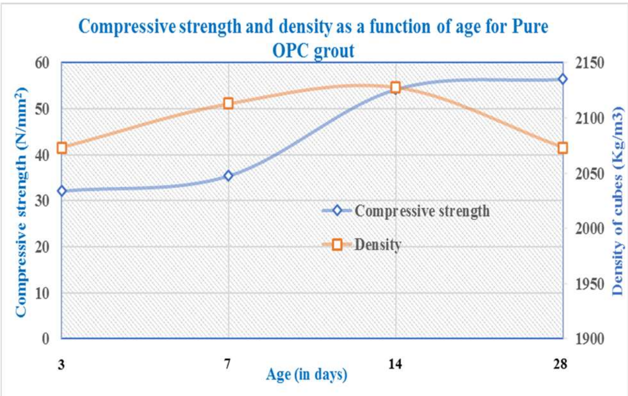


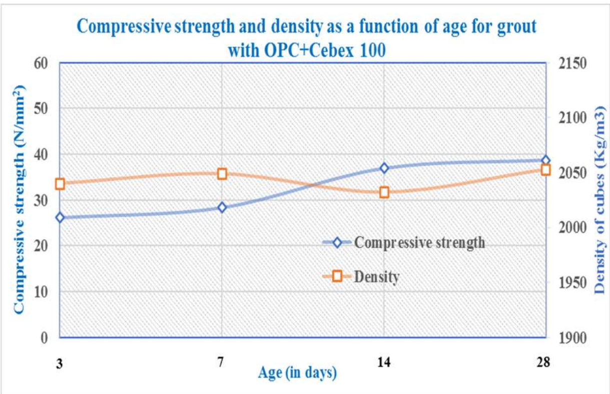
Figure 8. Variation of mix Temperature as a function of Time

Figure 9 (a), (b), (c) and (d) depicts the compressive strength and density as a function of age for the various trials conducted. It can be observed that grout when mixed with pure OPC, density increases over time, up to 14 days. Its density decreases after 14 days, returning to its original value of 3 days. With the addition of admixture, the density of the mix reduces as they help to control bleeding and shrinkage. Any cementitious grout when added with expansive admixture, a typical trend of reduction in the density is observed between 7 and 14 days. Such observed marginal reduction in the density is further gained between 14 and 28 days.

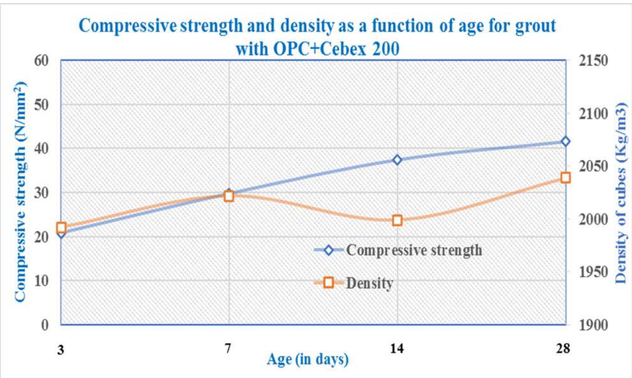
Compressive strength is higher in grouts with Pure OPC than in grouts with admixtures because Pure cement grout bleeds, reducing the w/c ratio and thereby increasing strength. Compressive strength decreases with the addition of admixtures, as they help to control shrinkage and bleeding. A similar upward trend is observed in grouts with Pure OPC, Cebex 100, and Cebex 200 from 3 to 28 days, while Cebex EN has a steady upward trend, suggesting that it is a stable compound in terms of strength gain.



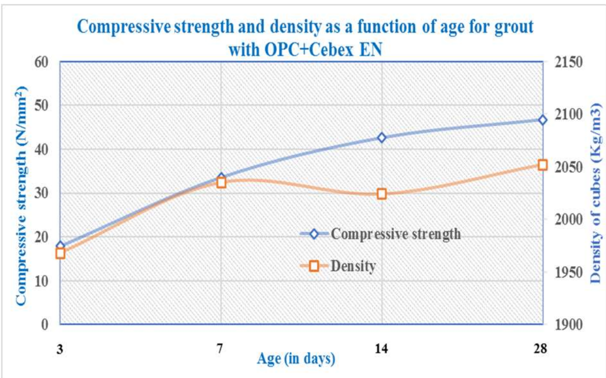
a) Grout with Pure OPC



b) Grout with Cebex 100



c) Grout with Cebex 200



d) Grout with Cebex EN

Figure 9. Variation of % gain of compressive strength and density as a function of age

5. Conclusions

The following conclusions were reached as a result of the research.

1. Cement grouts are used in the field of civil engineering and construction activities for wide applications such as sealing of cracks, protective coatings, soil anchoring applications, cable grouting for prestressed structures, repairs & rehabilitation of masonry and concrete structures, etc. to fill in the voids or gaps between the two elements to re-bond completely or to create a water-tight seal.
2. Grouts containing admixtures, such as Cebex EN, Cebex 100, and Cebex 200, are favoured because of their higher strength, better flowability, temperature and density consistency, and so on.
3. All of these admixtures, including Cebex EN, Cebex 100, and Cebex 200, help to reduce shrinkage. These admixtures are distinguished by the order in which shrinkage-reducing compounds are present. Cebex EN > Cebex 100 > Cebex 200.
4. When Cebex 100 comes into contact with atmospheric oxygen, it will form a water molecule since it is a gaseous expansive product with a hydrogen molecule. As a result of this, prestressing strands/tendons will deteriorate over years or decades.
5. The addition of admixtures to cementitious grouts results in a marginal reduction in compressive strength whereas reduction in density is negligible.
6. Cebex EN grouts are more stable than OPC and other admixtures because they have less variation in density and temperature. Furthermore, as opposed to Pure OPC grouts, grouts with admixtures show less bleeding.
7. When it comes to pumping the mixes, none of these admixtures poses a problem.
8. As compared to admixture-containing grouts, the time it takes for pure OPC grouts to set is nearly half of that of admixture-containing grouts.
9. The ability to mitigate shrinkage is the main reason for using these admixtures. Cebex EN grout is the only manageable grout when it comes to mix temperature, bleeding, density, and compressive strength. As a result, it is suggested for grouting.

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