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Performance of Cement Grouts and their Applications

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ABSTRACT

Cement grouts are extensively used in many of the construction areas such as coatings for prestressing strands/tendons, repair, and rehabilitation of masonry and RCC structures, grouting of soil, etc. They comprise a fluid mixture of cement, sand if used, water, and possibly, admixture(s) along with non-shrink additives. They are commonly used because such grouts possess higher compressive strength. Their rheology and properties can be easily modified by varying the mix proportions and dosages of the various components. Cement grouting is used on large-scale applications for grouting of cable ducts of prestressed bridges to fill in the voids or gaps between ducts and prestressing steel. These structures are vulnerable to deteriorations and damages such as strength and durability losses which occur due to corrosion and breaking of prestressing tendons/strands resulting from inadequate grouting and/or chloride attacks from airborne salts, use of de-icing salts, or even the use of sea sand in the concrete. Therefore, it is very much essential that this passive layer i.e. grout should be properly mixed and grouting should be carried out with utmost precautions. Proper material proportioning, mixing and placement is a must so that grout can fulfill the required properties after hardening. Pure cement grout bleeds thus lowering the w/c ratio but increasing strength. Thus, to improve its rheological properties like bleeding, shrinkage, strength, certain admixtures like Cebex 100, Cebex 200 and Cebex EN or equivalent will be added and their properties will be evaluated. This research intends to investigate the performance of cementitious grouts based on dosage and other additives at a major River Bridge Project in Goa.

Keywords – Bleeding, Cebex 100, Cebex 200, Cebex EN, Cementitious grouts.

1. INTRODUCTION

Cement grouts are used widely in the civil engineering discipline and construction activities such as sealing of wide cracks in gravity dams, shoring & soil stabilization, grouting of prestressed cable ducts, rehabilitation of masonry and concrete structures, etc. This is mainly because of the developments in the use of cementitious materials and chemical admixtures.

Cement grout is a blend of cement, sand (if used), water, and possibly, admixture(s) along with non-shrink additives in required mix proportions and dosages. Large scale application of cement grouting nowadays is for prestressed bridges especially for grouting of cable ducts, girder grouting, and coating of prestressed cables as the quantum of work involved is huge and requires utmost care and precautions to be taken. These prestressing strands/tendons are susceptible to corrosion resulting from inadequate grouting and/or chloride attacks from airborne salts, use of de-icing salts, or even the use of sea sand in the concrete which results in deterioration of tensile strength of cables due to contact with moisture present in the air, thus posing a major hazard in the long run. Therefore, this grout injected between the prestressing strands and duct should act as a final line of defense to protect the pre-stressing tendons/strands from corrosion. Several research studies were conducted to enhance the properties of the material and mechanical behaviour of grouts such as flow and bleeding characteristics, the time required for setting, chloride ion penetration, etc. using various filler elements such as fly ash, silica fume, ground granulated blast furnace slag (GGBS), micro cement, etc. in the grout mix.

Cement grouts are preferred because they possess stability and higher compressive strength. It is well known that the water to cement ratio (W/C) of a grout mix determines its compressive strength. Grouts possessing lower W/C ratios necessitate the incorporation of superplasticizers into the mix to achieve the required properties such as flow characteristics. Shrinkage is a critical factor in addition to compressive strength as it is one of the major issues with most of the grouts. Therefore, to reduce the effects of shrinkage and to ensure expansive properties to the grout, certain non-shrink chemical additives are required to be added to the grout mix. Pure cement grout bleeds thus lowering the w/c ratio but increasing strength. Thus, to improve its rheological properties like bleeding, shrinkage, strength, certain admixtures like Cebex 100, Cebex 200 and Cebex EN or equivalent will be added and their properties will be evaluated. The performance of cementitious grouts based on dosage and other additives was investigated at a major River Bridge Project in Goa in this research.

2. LITERATURE REVIEW

Various research studies were conducted on cement grouts by research scholars and their contributions reflecting specific results and methodology were observed and recorded.

Kim et.al. (2016) [1], evaluated the steel fiber-reinforced grout (SFRG) comprising ground granulated blast furnace slag (GGBS) for its fresh and hard state properties. Experiments were conducted to evaluate the properties of SFRGs by varying the types of cement and content of GGBS particles in terms of their volume. The incorporation of short smooth steel fibers reduced the flow, bleeding, and setting time of the SFRG mix. There was an increase in flow and setting time with the addition of GGBS with 40% replacement of cement by weight. GGBS in the grout mix helped to improve the chloride penetration resistance and the presence of steel fibers improved the flexural strength. Also, GGBS and steel fibers in the grout helped in the improvement of the crack resistance but reduced the flowability, bleeding, and time of setting. The percentage of steel fibres added to grouts was increased from 0.5 to 2 per cent by volume which caused a slight increase in flow time, a slight decrease in bleeding content, and initial setting time. With an improvement in the per cent addition of steel fibres, the flexural strength of SFRGs increased from 5.19 to 11.0 MPa. It was concluded that SFRGs with GGBS have suitable workability for substructures of offshore wind turbines made up of PSC.

Yoo et al. (2017) [2], examined how to use shrinkage-reducing admixture (SRA) to reduce the cracking capacity of post-tensioning high-performance grout (HG). The stated purpose of the HG mixture was for it to be fluid, exhibiting marginal bleeding and settling. To develop the HG mixture, different proportions of shrinkage-reducing admixture (SRA) were added to the cementitious components at 1% and 2% by weight. For comparison, an ordinary grout (OG) mixture was also used. The flowability of the HG mixture was comparable to that of the OG mixture, but it performed significantly better in terms of strength, bleeding, and settling. The presence of SRA in the HG mixture resulted in improved tensile and compressive strength of grout after 28 days, reduced values of shrinkage strain and maximum internal temperature resulting from the heat of hydration, and delayed cracking due to shrinkage. At all ages, complete filling of the ducts was ensured by these HG samples and impartment of the highest free shrinkage strain. While the OG mixture imparted the smallest shrinkage strain, good shrinkage cracking resistance, and insufficient filling of the ducts, leading to prestressing strands getting exposed to atmospheric air. An increase in the SRA content reduced the free shrinkage strain of HG, and SRA usage was highly efficient at a very early age in reducing the free shrinkage. They concluded that both the HG and OG mixtures achieved the requirement of flow duration. However, OG samples resulted in excessive bleeding and settling as compared to HG samples. They recommended that the HG mixture with 2% SRA is most appropriate for post-tensioning grout.

Kamalakannan et.al. (2018) [3], evaluated the fresh and hard state properties of several grout mixes. Various grout mixes used for the experimental purpose includes three Pre-Packaged Grout mixes (PPG), three Site-Batched Grout mixes (SBG), and one regular Ordinary Portland Cement grout (PCG) mix. A PPG blend and an SBG blend were also considered. The deciding parameters for the evaluation of properties include mixing speed at three stages and two ambient temperature conditions. The major properties evaluated include fresh state and set/hardened properties. Fresh state properties determined includes wet density, efflux time and retention, normal bleed, wick-induced bleed, and pressure bleed and set/hardened properties such as time of setting, compressive strength, and volume change. The consistency of results was verified by testing three batches for each grout material. Based upon the test results and observations, it was concluded that PT grouts which are commonly used by many developing countries including PCG, SBGs, and PPGs does not follow the requirements and specifications of PT grout standards proposed by the manufacturers. With the increase in ambient temperature from 15 ˚C to 30˚C, bleed resistance changes significantly based upon different grout materials. The optimal mixing speed was obtained as 1500rpm and 2500 rpm for SBG and PPG mixes, respectively. An increase in the ambient mixing temperature (at 15˚C and 30˚C) affects the compressive strength and setting time of grouts. An increase in the fineness content of grout particles increases the flow retention and bleed resistance of grouts which can be crucial for complete grout filling ability and reducing void formation. Based on these results, it was suggested that findings from the flow cone test alone cannot be considered the only option to assess the filling ability of thixotropic grouts for PT applications. It is required that the performance of grout mixes has to be evaluated under simulated site conditions before using them on a large scale in the field.

Sonebi and Perrot (2019) [4], demonstrated how the mix proportion of grout affects its characteristics such as flowability, rheology, and hydromechanical behaviour such as permeability and compressibility. The combined influence of the four mix compositions on various parameters such as fluidity, rheological characteristics, permeability, and compressibility were investigated using a factorial design technique by altering the water/binder ratio (W/B), percentage of limestone filler as a replacement for cement (LF), dosage of viscosity modifying admixture (VMA), and dosage of superplasticizer (SP). Various tests were conducted such as mini-slump, Lombardi plate test, forced bleeding test and, coaxial rotating cylinder viscometer to obtain the rheology and hydro-mechanical behaviour of the grouts comprising of cement. These tests are pertinent to mixtures containing W/B ranging from 0.35 to 0.42, LF as a cement replacement ranging from 12 to 45 per cent, VMA (percentage of binder) ranging from 0.02 to 0.7 per cent, and SP ranging from 0.3 to 1.2 per cent. The results of these parameters evaluated were presented in the form of polynomial regression to determine the primary factors and their influence on the properties measured. From the results, it was observed that mini-slump, permeability, and compressibility were significantly influenced by the W/B ratio. An increase in mini-slump, permeability and compressibility and, a reduction in the plate cohesion was observed with an increase in the W/B ratio. The increase in the dosage of superplasticizer resulted in increased values of mini-slump but lowered the values of plate cohesion meter, yield value, and plastic viscosity. Permeability was found to be reduced with an increase in the SP dosage. However, with an increase in the W/B ratio, permeability increased. Permeability and compressibility reduced for lower values of the W/B ratio and with an increase in the VMA dosage. The addition of limestone filler as a replacement for cement had a negligible influence on permeability and compressibility.

Zhang et.al. (2020) [5], evaluated the high-performance cementitious grouts for its flowability, mechanical behaviour, and dimensional stability by incorporating the plastic expansive agent (PEA). Methods such as XRD, TG-DSC, and SEM analysis were used to assess the hydration characteristics of the grouts. The flowability, mechanical behaviour, and dimensional stability of cementitious grouts were impacted by variations in PEA dosage. PEA will reduce the fluidity of the grout marginally while having no effect on the dosage variation. At lower dosage, it improves flexural and compressive strength, but at higher dosages, it dramatically reduces both. Furthermore, as the dosage rate and curing time are increased, the vertical expansion rate increases, resulting in excellent dimensional stability at an early age and a reduction in drying shrinkage. PEA can induce considerably denser and larger hydrates, as well as the formation of pores in the grout, resulting in a combined impact on properties, as demonstrated by the above XRD, TG-DSC, and SEM analyses. Vasumithran et.al. (2020) [6], conducted a research study wherein they used fine sand and fly ash as fillers in cement grouts and examined the flowability and mechanical behaviour of these grouts. Poor workability was observed in mixes comprising of fillers as the water-cement ratios were low. Therefore, to obtain the workable mix, a polycarboxylate ether-based superplasticizer was added. To determine the fresh and hard state properties in all of the grouts, silica fume was used to replace 10% of the cement mass, while fillers were used to replace 50% of the cement mass in some mixtures. An increase in the water-cement ratio rendered various issues such as excessive bleeding, instability of the mix, longer setting times, and reduced mechanical strengths. Silica fume in the grout mix led to poor workable mixes at low water-cement ratios but showed improved strength. Grouts made of fine sand and fly ash, on the other hand, showed poor early age strength. The use of fine sand as a filler in the mix helped to reduce shrinkage and increase water absorption. Mixes without fillers showed higher values of compressive, flexural, and bond strengths. Therefore, these fine fillers can be used effectively in the grout mix to improve the durability aspects.

3. MATERIALS

Some of the materials used in this study for cementitious grouts are listed below.

3.1 Cement

Ordinary Portland Cement (OPC) is the most common ingredient used for grouting. The cement used should be free from lumps and chemical impurities like chlorides and sulphates. It should possess the required setting time and its temperature should be less than 40˚C. Pozzolanic compounds should be avoided at all costs. Provisions of IS 269:1989 or 1489 (Part 1):1991 and 1489 (Part 2):1991 should be followed for cement grouting. For conducting trials, Ultratech cement-53 grade was used as shown in Fig. 1.

3.2 Water

The use of Potable water is desired in the preparation of grout without any presence of dissolved impurities. The use of seawater shall be strictly prohibited. The temperature of the water should be less than 5˚C. For the experimental purpose, water from the RMC plant was used conforming to the specifications as per IS 456:2000.

3.3 Admixtures

The admixtures are added to the grout mix to enhance the characteristics of the grout such as to increase flowability of material, reduce bleeding, prevent entrainment of air, and reduces shrinkage. All these additives must be free from chlorides, nitrates, sulphates, or other impurities which are likely to damage the prestressing steel or grout.

Different types of admixtures used in this study are described below.

3.3.1 Fosroc Cebex EN

Cebex EN admixture used for cement grouts where lower w/c ratio and expansion is required to be achieved. It is a powdered mixture and possesses plasticizing and hydrogen-free expansion properties. It imparts increased strength and durability. The main applications of this admixture include grouting of bed, ducts, joints, and non-shrink infilling. Fig. 2 shows Fosroc Cebex EN admixture.

3.3.2 Fosroc Cebex 100

This admixture is generally used for site-batched cementitious grouts where a lower w/c ratio and positive expansion are required. This can be used as a suitable pre-stressing grout admixture. This admixture helps to ensure stability and cohesion of the mix thus counteracting natural settlement and plastic shrinkage. Fig. 3 displays the admixture Fosroc Cebex 100.

3.3.3 Fosroc Cebex 200

Cebex 200 is also used for cement grouts to achieve a lower water/ cement ratio and positive expansion. Fig. 4 shows Fosroc Cebex 200 admixture.

Fig. 1 Ultratech Cement

Fig. 2 Foscroc Cebex EN

Fig. 3 Fosroc Cebex 100

Fig. 4 Fosroc Cebex 200

4. EQUIPMENTS

Pressure grouting is the commonly adopted method of grouting on-site wherein grout material is injected into the voids or spaces of ducts and prestressing cables/strands using grouting equipment. Fig. 5 and Fig. 6 show a Twin drum grouting mixer with an additional agitator (pneumatic pressure-based) and a Single drum grouting mixer (screw conveyer-based) respectively.

Fig. 5 Twin drum grouting mixer with additional agitator

Fig. 6 Single drum grouting mixer

5. THE METHODOLOGY ADOPTED ON SITE

The flow diagram of the grouting process is presented in Fig. 7.

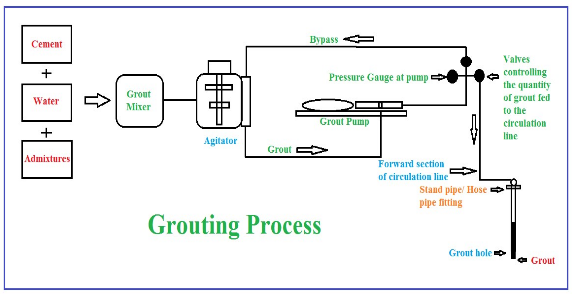

Fig. 7 Grouting process

The field grouting process involves 3 operations.

i. Mixing proportions as per the mix design
ii. Maintaining the required pressure
iii. Safety precautions for pressure relief

Selected materials as per the mix design are mixed with the admixture of known dosage into a mixing device. The contents are thoroughly mixed for about 2-3 minutes and require continuous agitation till the grout mix is pumped. A pressure of 0.5 MPa is recommended. However, the minimum pressure required is 0.3 MPa. Before grouting, the mix has to strain through a grout strainer to avoid choking. As a precaution, the maximum pressure is ensured not to cross 1 MPa. The process shall be stopped once the grout resists penetration. This can be ensured by observing the free movement of the grout at the other end and the pumping point.

6. EXPERIMENTAL WORK

An experimental study was conducted which includes evaluation of the grout mix properties such as compressive strength. In this work, cubes of 100mm X 100mm X 100mm were cast using grout mix which were then demoulded after 24 hours and kept for normal water curing. These cubes were tested at 3, 7, 14, and 28 days respectively. Fig. 8 shows the various experiments conducted in the laboratory such as temperature measurement of grout mix, mixing of grout, casting of cube specimens, normal water curing, and testing of cube specimens (compression test). Table 1 shows a mix design summary of various trials conducted in this study.

(a)Temperature measurement (b) Mixing of grout

(c) Normal Water Curing (d) Compression Test

Fig. 8 Various experiments conducted in the laboratory

Table 1 Mix design summary of various trials conducted

Mix Speci-fication	With Pure OPC	OPC + Cebex EN	OPC + Cebex 100	OPC + Cebex 200
W/c ratio	0.4	0.4	0.4	0.4
Admix-tures	-----	225 gms Per 50 Kg of Cement	225 gms Per 50 Kg of Cement	225 gms Per 50 Kg of Cement

7. RESULTS AND DISCUSSIONS

The major goal of this study is to recommend additive mix proportions and dosages for grouting prestressed cable ducts at the Zuari River Project in Goa. This topic illustrates the comparison of test results of various trials conducted. Table 2 shows the temperature measurement results of source materials and grout mix for various trials conducted. Table 3 shows the results of the compression test.

Table 2. Temperature measurement results

Material	Temperature ˚C
Cement bag	< 40˚C
Water	< 5˚C
Grout mix at the inlet	< 16˚C
Grout mix at the outlet	< 25˚C

Table 3 Compression test results

Mix Speci-fication	Average 3 days strength (MPa)	Average 7 days strength (MPa)	Average 14 days strength (MPa)	Average 28 days strength (MPa)
With Pure OPC	32.15	35.44	54.27	56.47
OPC + Cebex EN	17.87	33.57	42.62	46.75
OPC + Cebex 100	26.20	28.40	36.93	38.73
OPC + Cebex 200	20.83	26.57	35.2	40.07

8. GRAPHS

Fig. 9 shows the variation of density with age for the trials conducted. With the addition of admixtures, the density of the mixture reduces. Mix with pure OPC shows an increasing trend of density up to 14 days. After 14 days, its density again reduces to the initial value of 3 days.

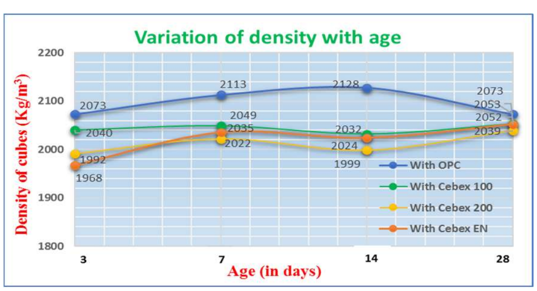

Fig. 9 Variation of density with age

Fig. 10 presents the variation of % gain of compressive strength with age for the trials conducted. It can be deduced that compressive strength is higher in grout with Pure OPC as compared to grouts with admixtures because the Pure cement grout bleeds more than 2% which lowers the w/c ratio and hence strength increases. With the addition of admixtures, strength decreases as they help to control shrinkage and bleeding. Pure OPC, Cebex 100 and Cebex 200 follow a similar increasing trend whereas Cebex EN follows a gradually increasing trend from 3 to 28 days indicating it as a stable compound with respect to strength gain.

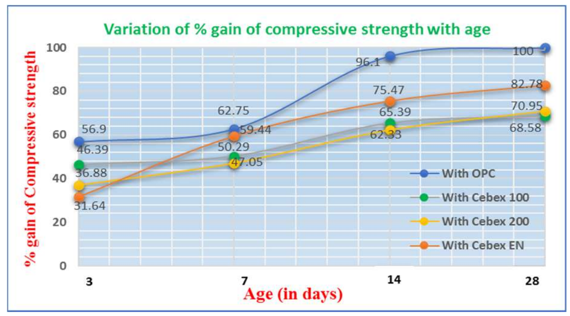

Fig. 10 Variation of % gain of compressive strength with age

Fig. 11 shows the variation of mix temperature with time for the trials conducted. In the case of grout with pure OPC, temperature increases suddenly up to 60 minutes which again decreases beyond 150 minutes, and then tries to stabilize. Whereas, for Cebex EN there is a gradual increase of temperature up to 60 minutes. Beyond 60 minutes it tries to stabilise. Therefore, temperature and heat of hydration are maintained in grout with Cebex EN. Thus, Cebex EN behaves as a stable grout with respect to mixing temperature.

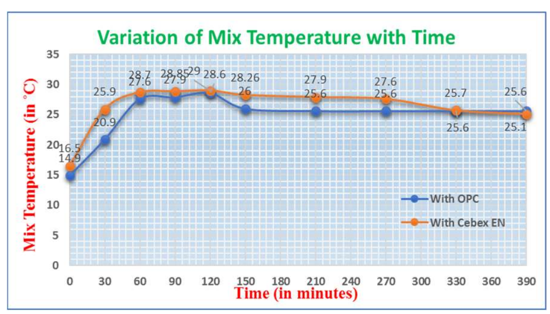

Fig. 11 Variation of mix temperature with time

9. CONCLUSIONS

From the study conducted, the following concluding points have been noted.

1. Cement grout is a blend of cement, sand (if used), water, and possibly, admixture(s) along with non-shrink additives in required mix proportions and dosages used to fill in the voids or gaps between the two elements to re-bond fully or to create a water-tight seal. They are used for repair, and rehabilitation of masonry and RCC structures, shoring & soil stabilization, grouting of prestressed cable ducts, sealing of wide cracks in gravity dams, etc.
2. Grouts with admixtures such as Cebex EN, Cebex 100, and Cebex 200 are preferred because they possess higher strength, good flowability, consistency with respect to temperature and density, etc.
3. All these admixtures such as Cebex EN, Cebex 100, and Cebex 200 are shrinkage-reducing compounds. The main difference between these admixtures is that they consist of shrinkage reducing compounds in the descending order of Cebex EN > Cebex 100 > Cebex 200.
4. Grouts with Cebex EN are stable as they do not show much variation with respect to density and temperature as compared to OPC and other admixtures but show higher strength. Also, lesser bleeding is observed for grouts with admixtures as compared to that of Pure OPC grouts.
5. There is no issue with respect to the pumping of the mixes with any of these admixtures.
6. The time taken by grouts for the setting is almost 50% in the case of pure OPC grouts as compared to grouts containing admixtures.
7. These admixtures are mainly used because of their shrinkage-reducing properties. It can be concluded that grout with Cebex EN is the only manageable grout with respect to density, compressive strength and mix temperature. Therefore, its use is recommended for grouting. Further studies on this topic such as durability studies i.e. shrinkage and permeability are in progress.

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