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Evaluation of Performance of Grout Materials in Protection of Prestressing Steel

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Prestressing cables are widely used in huge constructions like buildings and bridges. Corrosion of prestressing steel is more dangerous than the corrosion of reinforcing steel in concrete. Stress corrosion is propagated due to corrosion initiation in prestressing steel under stressed condition. Corrosion resistance of the prestressing steel depends upon the grout material. In this investigation three types of grout materials namely cement grout with non-shrinking admixture, polyurethane foam and epoxy grout were assessed for its suitability within the prestressing cable duct. The performance of grout materials to protect against prestressing steel corrosion was evaluated by different electrochemical techniques such as OCP measurements, anodic polarisation test and impressed voltage technique. The mechanical property of the different grout materials were test at room and elevated temperature. Among the three grouts, epoxy based grout system showed better corrosion resistance properties.

Keywords: Cement grout; Epoxy grout; Polyurethane Foam; corrosion studies

1. INTRODUCTION

In prestressed concrete structures, corrosion attack is generally protected by high alkalinity provided by cement based grout. Thus a passive layer on the steel surface provides adequate corrosion resistance. The long-term durability of this resistance relies on the stability conditions necessary for the passive layer [1]. In post-tension concrete structures the grout protecting the cables establishes the durability to the cables. The defects included in grout within the ducts, admixture in the grout and other reactants causing the tendon to initiate localized corrosion leading to corrosion failure [2].

The durability of prestressed concrete bridges primarily depends on the steel wire cables. Several disorders in these bridges are well known, such as fracture of these cables by stress corrosion cracking due to water penetration in the prestressing ducts. This water can contain various aggressive constituents with respect to corrosion (like chlorides). Its penetration inside the duct is due to the presence of sealing defects of the structure or in the concrete (like cracks). The second category of defects relates to the cement grout injection, which protects cables. This occurs due to a degradation of the grout in contact with water (problems of bleeding and segregation) leading to brittle fractures of steels [3]. Prestressing cable embedment in grout is affected by its own factors also, like porosity and internal grains [4,5].

Various grout materials with admixture or polymer based were adopted [6-8]. The suitability of the grout material is required to be analysed. Laboratory evaluation such as anodic polarization, applied voltage test, open circuit potential, bond performance would be beneficial to assess the different grout systems. In engineering application the main factor to be considered is the bond strength. Cement grout and epoxy grout are mostly used as grout materials and surrounding the steel and duct. Hence it must be able to understand the bond performance between prestressing cables and grouts after accelerated corrosion [9]. To find out the bond strength of the concrete generally pullout test method is adopted. The purpose of pullout tests was mainly to evaluate the effect of the embedment length, anchor surface properties and grout mixture on the bond strength behaviour. The penetrability due to filtration tendency of cement-based grouts and their high performance was reported [10,11].

The objective of the present investigation is to evaluate the three types of grout materials such as cement grout with non-shrinking admixture, polyurethane foam and epoxy grout for their suitability for prestressing steel with respect to corrosion resistance properties by different electrochemical techniques.

2. EXPERIMENTAL PART

2.1. Materials

2.1.1. Grout Materials

Three types grout materials were used namely cement grout with non-shrinking admixture, polyurethane foam and epoxy grout.

2.1.2. Prestressing steel

Prestressing steel consists of seven wire strand (12.5 mm dia.) was used and the bottom edge of the strand was sealed.

2.2. Methods

2.2.1. Anodic Polarization test

Seven wire strands (12.5 mm dia.) of length 150mm was used and the bottom edge of the strand was sealed. The prestressing strand was embedded centrally in the grout. Then the specimen is subjected to anodic polarization test in 0.04N NaOH solution. During the test various percentage of chloride such as 10,000 & 30,000 ppm are added in the NaOH Solution. Potential is monitored using high impedance multimeter with SCE as reference electrode. After getting stabilized potential the test specimen was anodically polarized at a constant current density of 290 $\mu A/cm^2$ using platinum as a counter electrode. Potential with time was followed for 5 minutes.

2.2.2. Impressed voltage test

Cylindrical grout specimen of size 75mm diameter and 150mm height were cast with centrally embedded prestressing strand. During casting, the moulds were mechanically vibrated. After 24 hours, the cylindrical specimens were demoulded and allowed for curing as per the grout material supplier's instruction. After curing, the specimens were subjected to applied voltage test by applying a constant 12V DC to the system. The variation of current was recorded with time until the crack is visible thereafter. Fig.1 shows the schematic of impressed voltage test arrangement. The time taken for initiation of first crack can be considered as a measure of their relative resistance against chloride permeability and reinforcement corrosion.

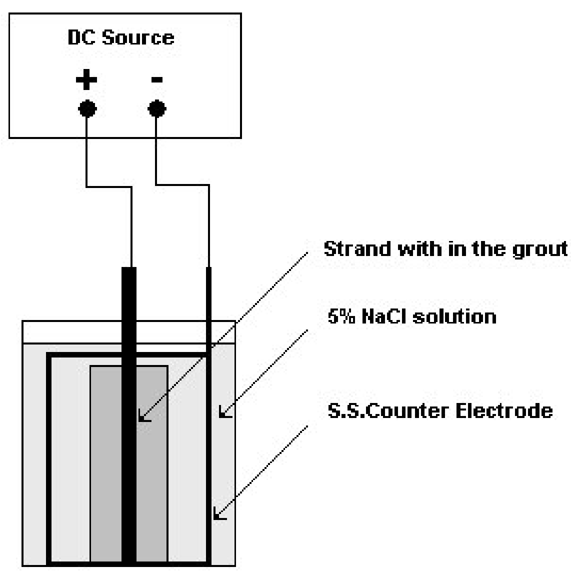
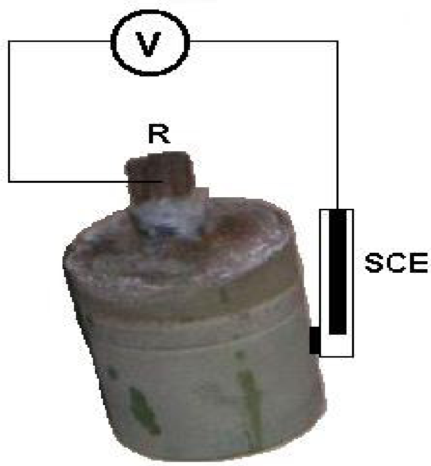


Figure 1. Schematic of impressed voltage test arrangement

2.2.3. Open circuit potential

Cylindrical grout specimen of size 50 mm diameter and 50 mm height were cast with centrally embedded prestressing strand. The positive terminal of high impedance voltmeter is connected to prestressing strand specimen and negative terminal (common) to SCE as reference electrode in the half-cell. The surface of the grouted specimen was sub-divided into various nodal points. The reference electrode was placed on the nodal point and the corresponding potentials were recorded. The schematic of OCP measurements is shown in Fig.2.



R	:	Prestressing strand
V	:	Digital multimeter
SCE	:	Saturated Calomel Electrode in half cell

Figure 2. Schematic for OCP measurements

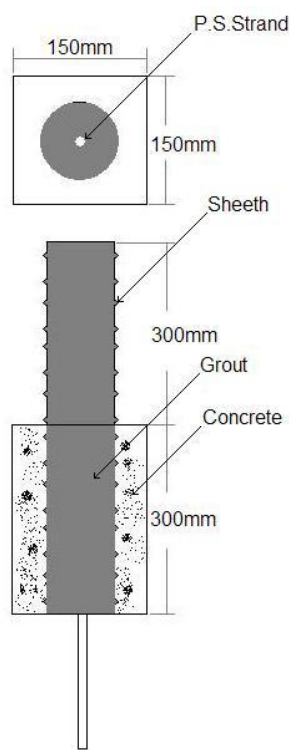


Figure 3. Schematic of Pullout specimen

2.2.4. Bond performance

Pullout specimen as per Fig.3 was moulded with centrally embedded prestressing strand. Following are the materials used for making test specimen.

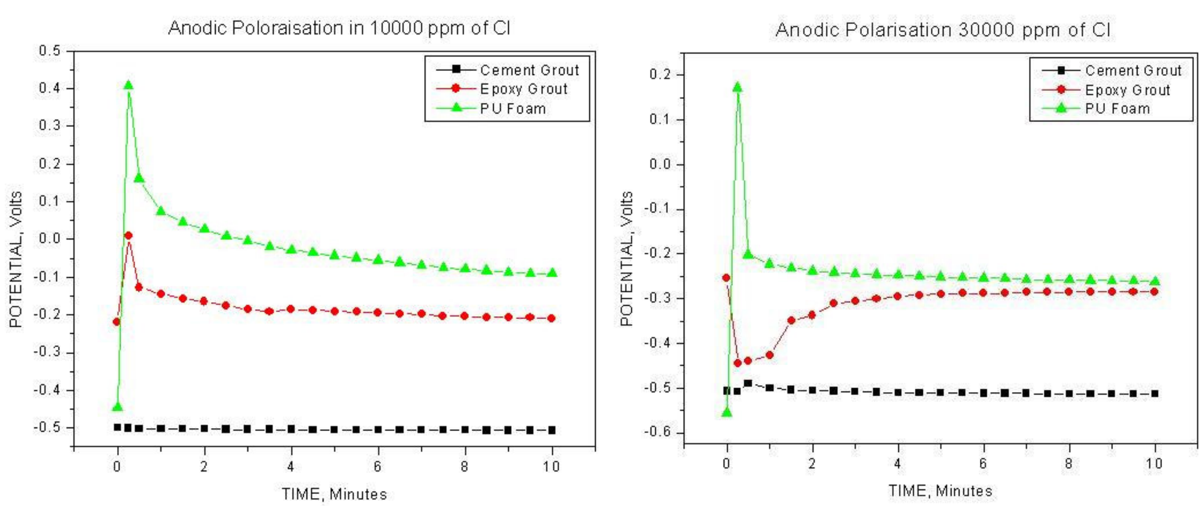
1. Ordinary Portland cement with non-shrinking admixture
2. Epoxy grout – Sikadur 53, two-pack material

12.5 mm diameter prestressing strand is centrally inserted in a cable sheath containing grout material. Then the whole assembly surrounded by a helical spring was cast into a concrete mould of size 150X 150X300 mm size block and subjected to curing in water for 28 days. After curing, the specimens were taken out and subjected to pull out bond strength test. The pullout specimen were heated and the bond performance were studied at the elevated temperature namely 50± 2°C.

3. RESULTS AND DISCUSSION

3.1. Anodic polarisation studies

Anodic polarisation curves for steel in different grout materials admixed with 10000 and 30000 ppm of chloride are shown in Fig.4(A) and (B) respectively. It was observed from the figures that cement grout showed more negative values than the other two systems. Cement grout fails at 10000 ppm of chloride. On the other hand, epoxy grout and PU foam grout materials able to maintain the passivity even at the 30000 ppm of chloride indicating the better corrosion resistant properties. The better corrosion property of the various grouts on the basis of anodic polarisation studies follows the order: Epoxy grout > Polyurethane foam > Cement grout.



(A) (B)

Figure 4. Anodic polarization curves for prestressing steel in different grout materials admixed with chloride (A) 10000 ppm Cl^- ; (B) 30000 ppm Cl^-

3.2. Impressed voltage test

The performance of the grout materials under impressed voltage test is shown in Fig.5. It was observed that the specimen was cracked after 48 hours of exposure indicating the highly permeable nature of the cement grout materials. In the case of PU foam, initially the chloride ingress is more and the anodic current recorded as 40 to 80 mA. The leaching of corrosion product was obtained within 150 hours of the exposure.

In the case of epoxy grout, the current flow was observed to be in terms of μA and there is no sign of crack even after a month of exposure indicating its impermeability. The epoxy system showed a lesser anodic current when compared to PU foam and cement grout. PU foam and cement grout have failed even in 2 days (initiated cracks) where as the epoxy system is intact even after 30 days of exposure.

On the basis of impressed voltage technique the tendency in maintaining the impermeability for the various grouts follows the order: Epoxy grout > Polyurethane foam > Cement grout. The same order was already noticed in anodic polarisation studies also.

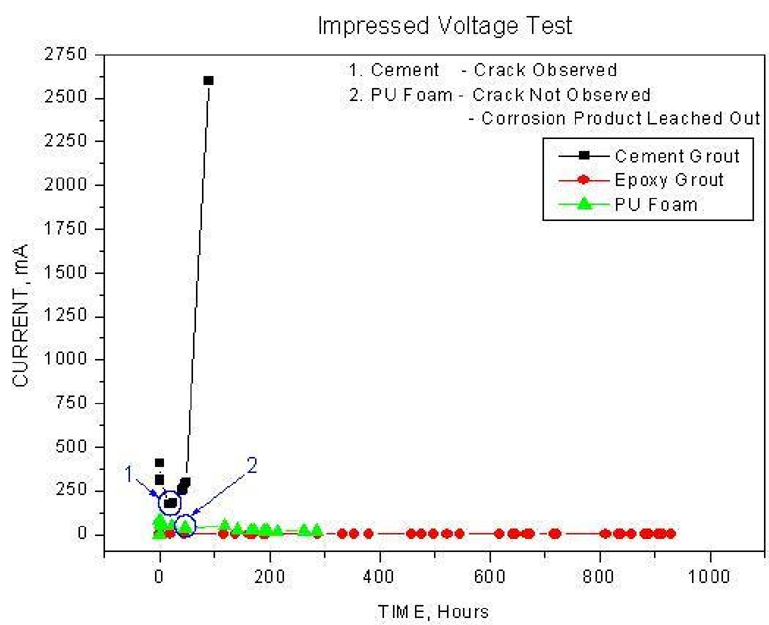


Figure 5. Performance of different grout materials under impressed voltage test

3.3. Open circuit potential measurements

Half-cell potential measurements in grout qualitatively indicate the corrosion condition of prestressing strand. Figs. 6, 7 & 8 shows the potential-time behaviour of cement grout, PU foam and epoxy grout respectively over a period of 120 days immersed in 3% NaCl aqueous solution.

Corrosion normally progressed in three phases such as corrosion initiation, propagation and failure. In the first phase, the time taken for initiation of corrosion on the embedded steel depends on the surrounding materials. Fig.6 shows the performance of cement grout with non-shrinking admixture.

The trend of OCP upto 80 days behaved like corrosion initiation period and there after looks like a propagation period.

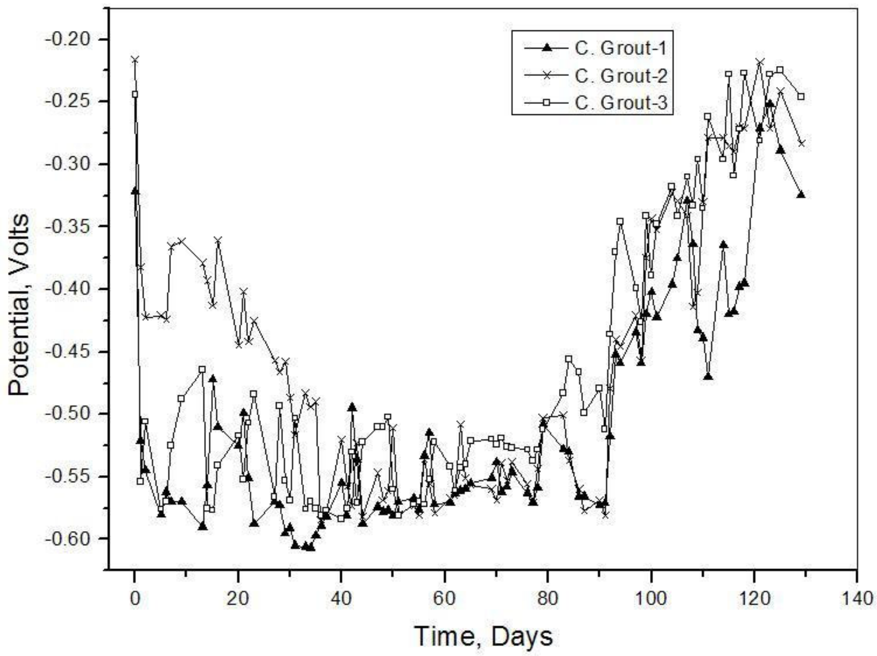


Figure 6. Potential-time behaviour of prestressing steel in cement grout

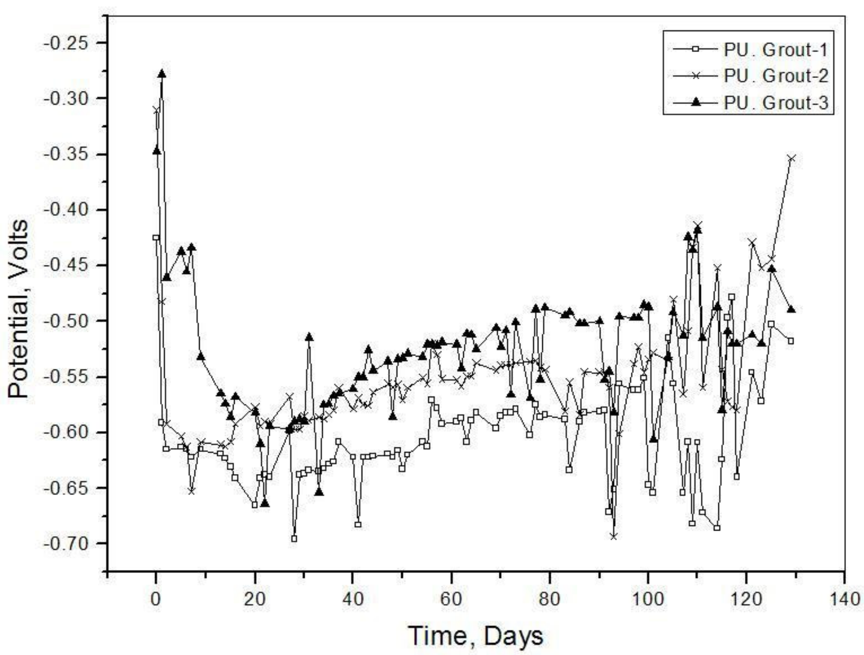


Figure 7. Potential-time behaviour of prestressing steel in PU Foam

In the case of PU Foam, which is depicted in the Fig.7 the initiation period is extended up to 110 days. This shows the PU foam has certain extent of protection than the cement grout.

The potential-time behaviour of epoxy-grouted specimens was illustrated in the Fig.8, which lies in the initiation period only and showed a passive behaviour throughout. The epoxy grout can easily be comparable with other two systems such as cement grout and PU Foam and shows better barrier protection.

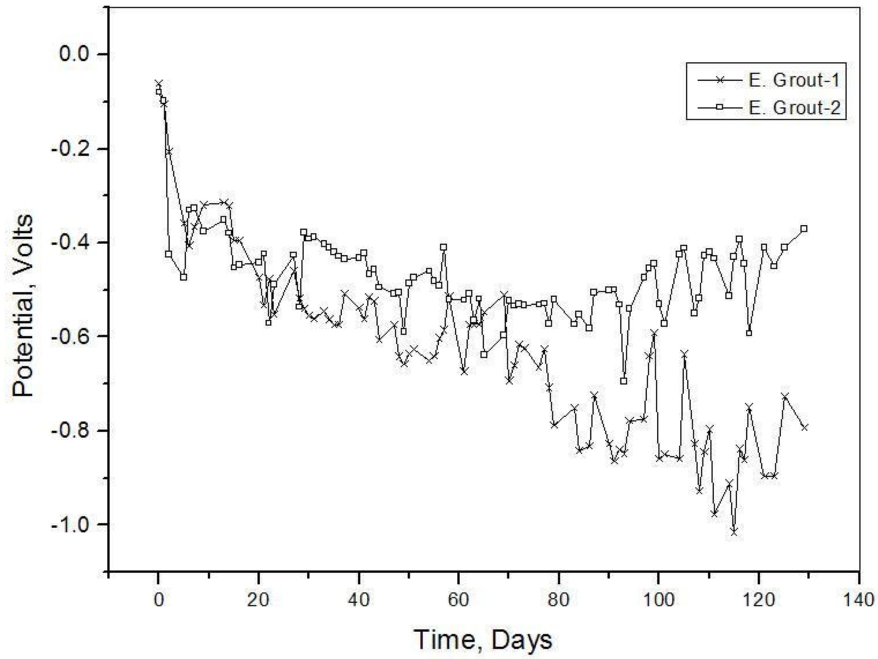


Figure 8. Potential-time behaviour of prestressing steel in epoxy grout

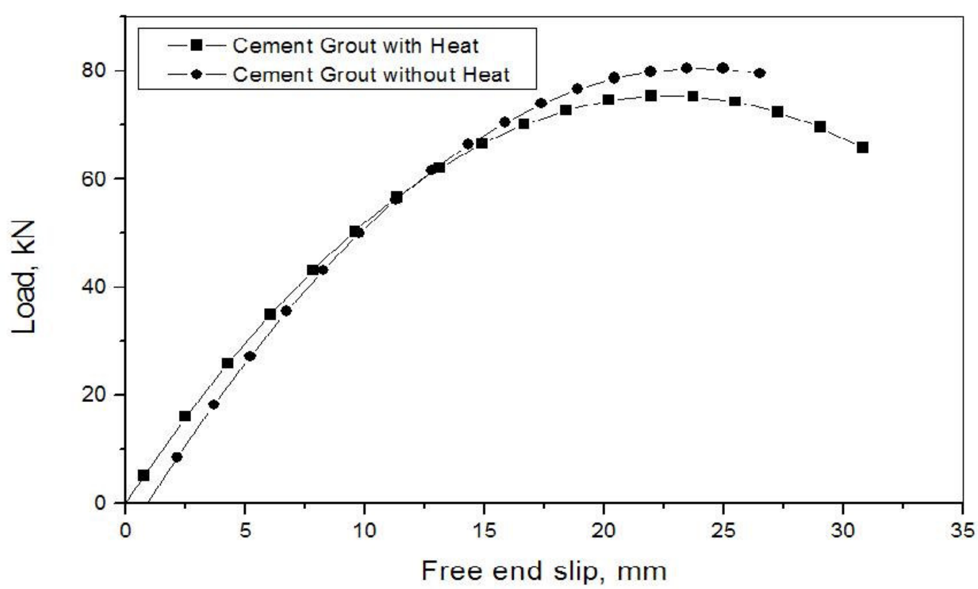


Figure 9. Bond strength characteristics of cement grout with and without heat

3.4. Bond Performance

Figs.9 and 10 shows the load vs. slip behaviour of cement grout and epoxy grout system respectively. It was observed from figures that the epoxy grout showed higher bond strength than cement grout. Further, the bond strength values are not much affected when increasing the temperature to 50^{o}C. At room temperature the epoxy grout performed better than cement grout but at elevated temperature cement grout performed better than epoxy grout. The better bond strength of the epoxy grout indicates the good adherence between steel and grout materials.

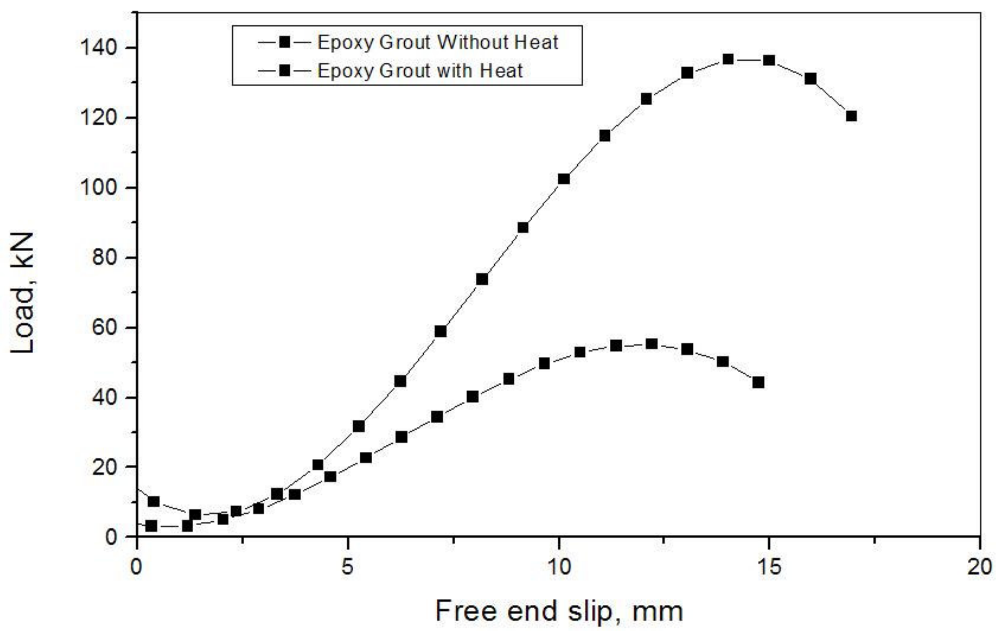


Figure 10. Bond strength characteristics of epoxy grout with and without heat

4. CONCLUSIONS

Anodic polarization technique is an effective tool to find out the tolerable limit of chloride. The epoxy grout showed higher tolerable limit of chloride than the PU foam and cement grout. Impressed voltage test is used as an accelerated evaluation for strand embedded in grout. Epoxy grout performed uncracked for more than 30 days of exposure. The PU foam and cement grout failed within 2 days. Pull out performance was conducted for identifying the mechanical properties of the grout materials under temperature variations. The cement grout has not shown any variation under the elevated temperature. In the case of Epoxy grout the bond strength is higher than the cement grout but in elevated temperatures a slight decrease of bond strength than the cement grout was observed.

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