# Determining the Concrete's Ability to Resist Chloride Ion Penetration at the Port of Imam-Khomeini

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## Introduction

This paper presents the laboratory test results of a concrete mixture designed to prevent the corrosion of marine structures at the Port of Imam-Khomeini in the north of Persian Gulf in Iran. The aim of this project is to repair the concrete pile and berths deteriorated by seawater attack and the completion of four other berths.

Steel corrosion in reinforced concrete is an electrochemical process. In ordinary condition, the concrete cover, with a pH between 12 and 13, is a very good protection for the steel reinforcement. But in marine structures the existence of saline water and oxygen (dissolved in the water or in the air) may cause problem. When the penetrability of concrete cover is high, or when a small crack exists somewhere in the concrete cover, the corrosion of steel reinforcement occurs in two stages. In the first stage, the chloride ion penetrates in to concrete cover and by changing its pH, constitutes a galvanic cell. In the second stage oxygen attacks to the steel reinforcement. This process is within the increase of the volume so the concrete cover cracks more, and the deterioration continues more rapidly.

The salinity of Persian Gulf $40‰ (40\,gr/litre)$, which is very high in comparison with the salinity of the oceans $(34-35‰)$ and many other seas, is a reason to increase corrosion. Also the warm climate of this region may increase the dissolved air in seawater.

But the main reason of this deterioration is the initial concrete mixture design, that is not well evaluated. With a water-cement ratio of 0.55 to 0.60, the concrete cover of piles and berths are highly penetrable. Also the concrete cover thickness of the structures are less than recommended values. In the other hand, a Portland cement type V, whose penetrability to chloride ion is 2.5 times more than the Portland cement type I, is also used in the concrete mixture.

To repair the detoriated concrete pile and berths, a shotecrete[1] mortar including Portland cement type II, water-cement ratio equal 0.4, and micro-silicate, with a compressive strength of $500\,kg/cm^2$ is designed. Now question is: "if this new concrete mixture is impermeable enough to prevent the sea water penetration and if any other chemical products such as Penetron[2] is also needed".

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[1] Shotcrete is mortar or concrete pneumatically projected at high velocity onto a surface. Since shotecrete is generally used without exterior forms, the mixture should have a minimum slump so that sagging of the shotcrete is avoided.

[2] Penetron is a cementitious capillary waterproofing material, which is applied as a coating to the surface of concrete structure in order to reduce its penetrability to chloride ion.

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In marine structures the existence of saline water and oxygen may cause problem. Also the warm climate of the region may increase the dissolved air in seawater. But a fundamental reason of the deterioration is the problem of concrete mixture and that is what has happened in the port of Imam-Khomeini in the nord of Persian Gulf in Iran

With a water-cement ratio of 0.55 to 0.60, the concrete cover of piles and berths were highly penetrable. Also the concrete cover thickness of the structures was less than recommended values. A Portland cement type V, whose penetrability to chloride ion is 2.5 times more than the Portland cement type I, was also used in the concrete mixture.

To solve this problem, a concrete shotecrete mortar including Portland cement type II, water-cement ratio equal 0.4, and micro-silicate, with a compressive strength of $500\, kg/cm^2$ was designed. The question now was "if this concrete mixture was impermeable enough to prevent the sea water penetration and if any other chemical products such as Penetron[1] was also needed".

This article is devided in two sections. In the first section, an apparatus that was constructed at Tafresh Campus of AmirKabir university of technology is presented. The test procedure is according to A.S.T.M. C 1202-91. This test method consists of determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions.

In the second part, four different concrete mixtures, prepared at the port of Imam-Khomeini, are tested and compared with each other. The test results shows that the designed shotecrete mortar mixture, with a very low permeability is suitable. Several other conclusions are also obtained.

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Steel corrosion in reinforced concrete is an electrochemical process. In ordinary condition, the concrete cover, with a pH between 12 and 13, is a very good protection for the steel reinforcement. But in marine structures the existence of saline water and oxygen (dissolved in the water or in the air) may cause problem. When the penetrability of concrete cover is high, or when a small crack exists somewhere in the concrete cover, the corrosion of steel reinforcement occurs in two stages. In the first stage, the chloride ion penetrates in to concrete cover and by changing its pH, constitutes a galvanic cell. In the second stage oxygen attacks to the steel reinforcement. This process is within the increase of the volume so the concrete cover cracks more, and the deterioration continues more rapidly.

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## Test Method

First, an apparatus including a vacum saturation apparatus, a 500 mL separatory funnel, a 1000 mL beaker, a 250mm inside diameter vacuum desiccator, a vacum pump capable of maintening a pressure of less than 1 mm Hg in desiccator, a vacum gage accurate to +/- 0.5 mm Hg and coating apparatus and materials is mounted and tested accurately at Research Center of Tafresh Camus of AmirKabir University of Technology.

The test procedure is according to A.S.T.M. C 1202-91 and AASHTO T 259. This test method covers the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions.

The test method consists of monitoring the amount of electrical current passed through 2-in. (51-mm) thick slices of 4-in. (102-mm) nominal diameter cores or cylinders during a 6-h period. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, indicates the chloride ion penetrability of the sample. Table 1 shows the relation between the charge passed and the chloride ion penetrability.

**Table 1 - Chloride Ion Penetration Based on Charge Passed**

| Charge Passed (coulombs) | Chloride Ion Penetrability |
|---|---|
| >4000 | High |
| 2000 – 4000 | Moderate |
| 1000 – 2000 | Low |
| 100 – 1000 | Very Low |
| <100 | Negligible |

## Characteristics of Samples

As mentioned below, four different concrete mixtures and two samples from each type have been used in this test.

- Samples No. 09054-a & b: Ordinary concrete mixture as used in port area outside the wharf.
- Samples No. 09072-a & b: Ordinary concrete mixture as used in port area outside the wharf with a coating of Penetron.
- Samples No. 62978-a & b: Special concrete mixture including micro-silicate, designed for this project.
- Samples No. 04406-a & b: Special Concrete mixture including micro-silicate with a coating of Penetron.

## Test Results

The temperature and electrical conductance are measured for a period of 6 hours with the 5 minute intervals for each specimen. Figures 1 to 8 present the test results.

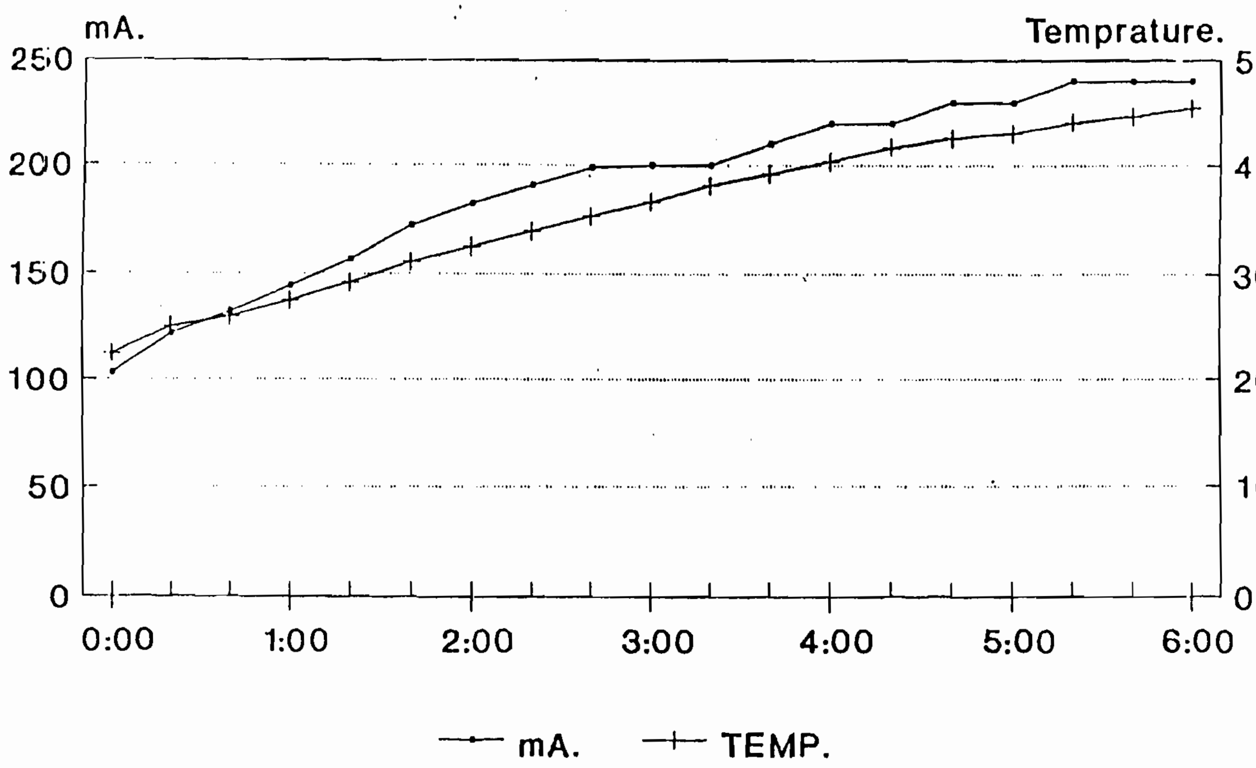


Figure 1 - Temperature and electrical conductance of the sample No. 09054-a

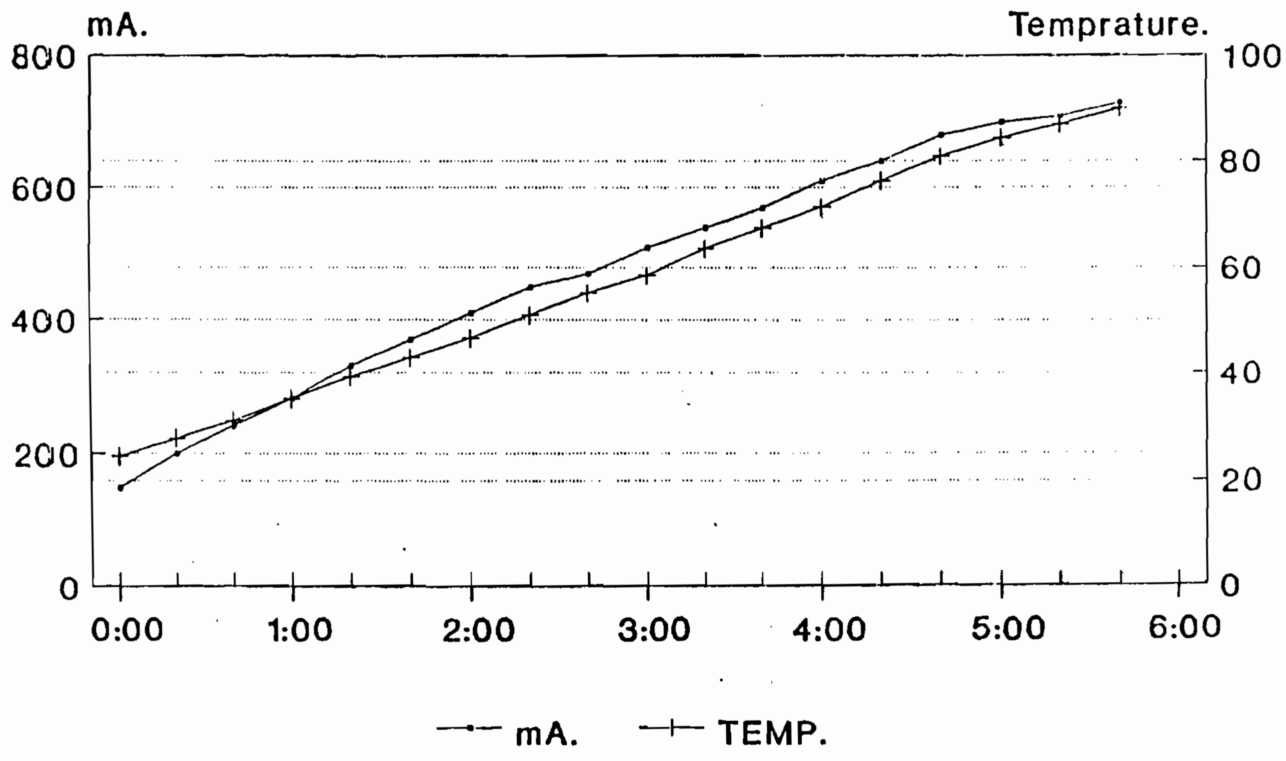


Figure 2 - Temperature and electrical conductance of the sample No. 09054-b

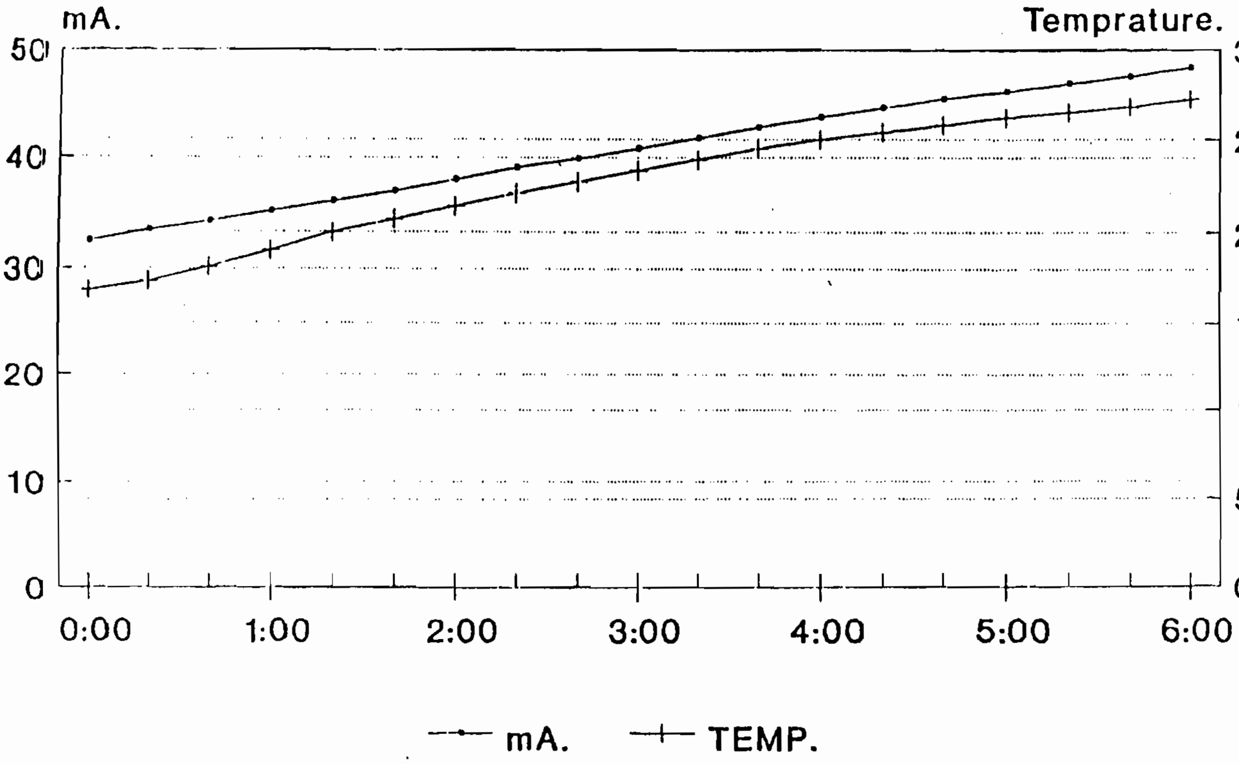


Figure 3 - Temperature and electrical conductance of the sample No. 09072-a

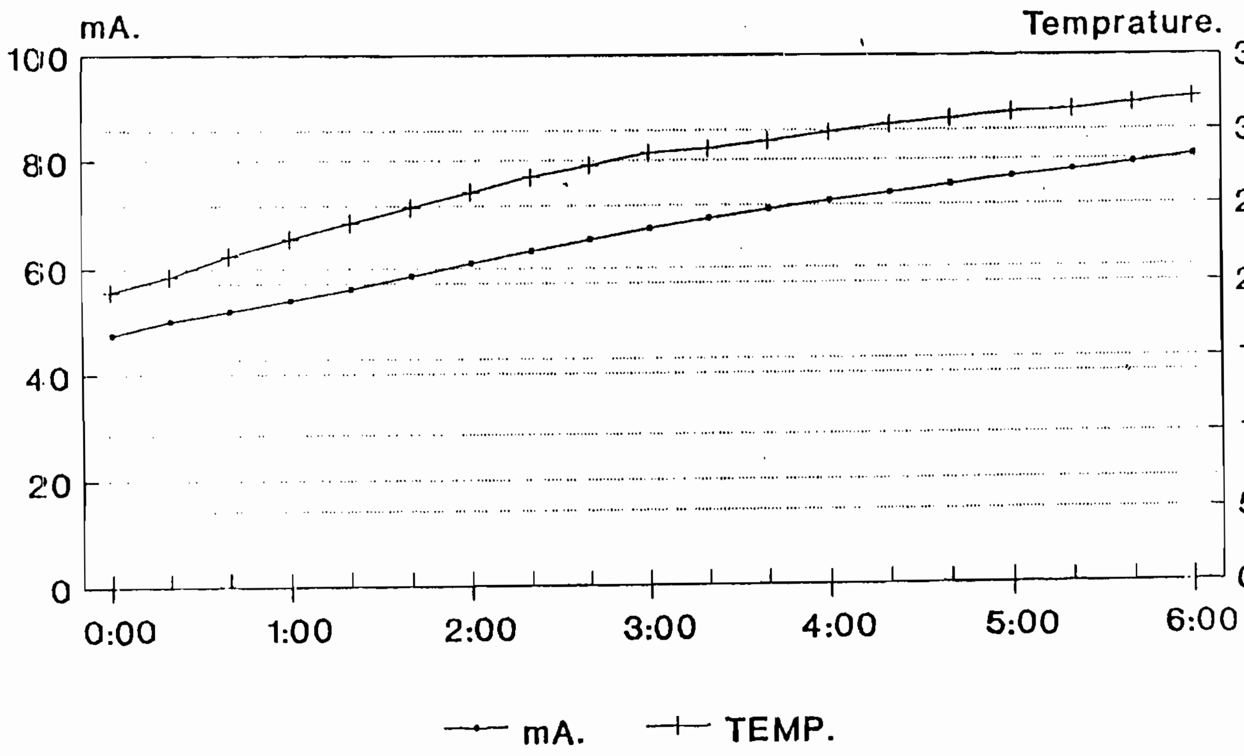


Figure 4 - Temperature and electrical conductance of the sample No. 09072-b

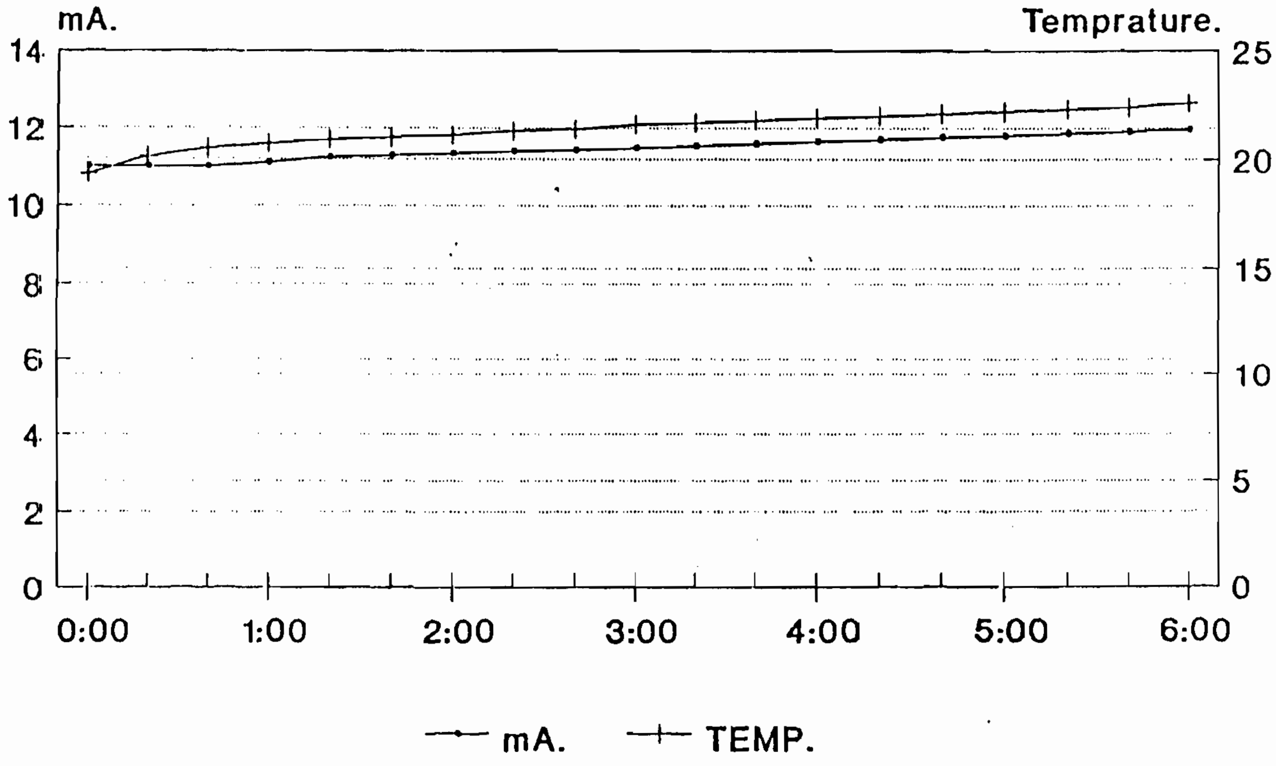


Figure 5 - Temperature and electrical conductance of the sample No. 62978-a

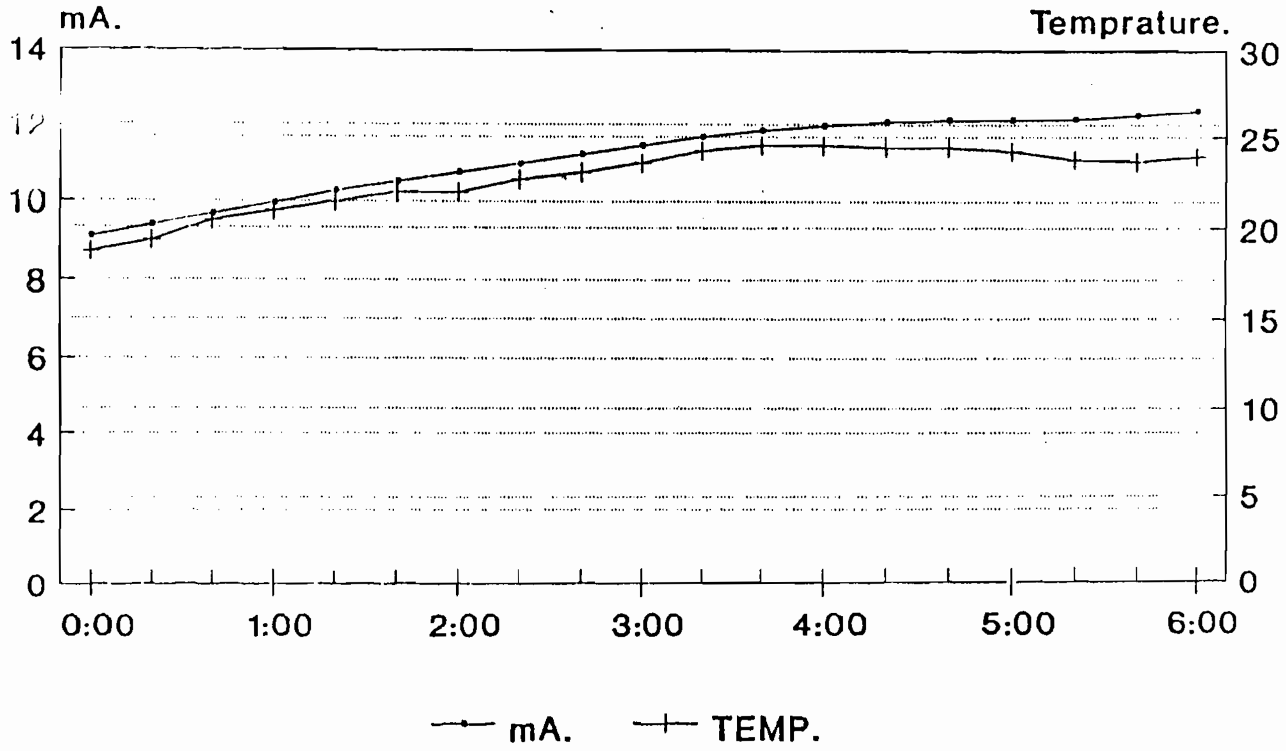


Figure 6 - Temperature and electrical conductance of the sample No. 62978-b

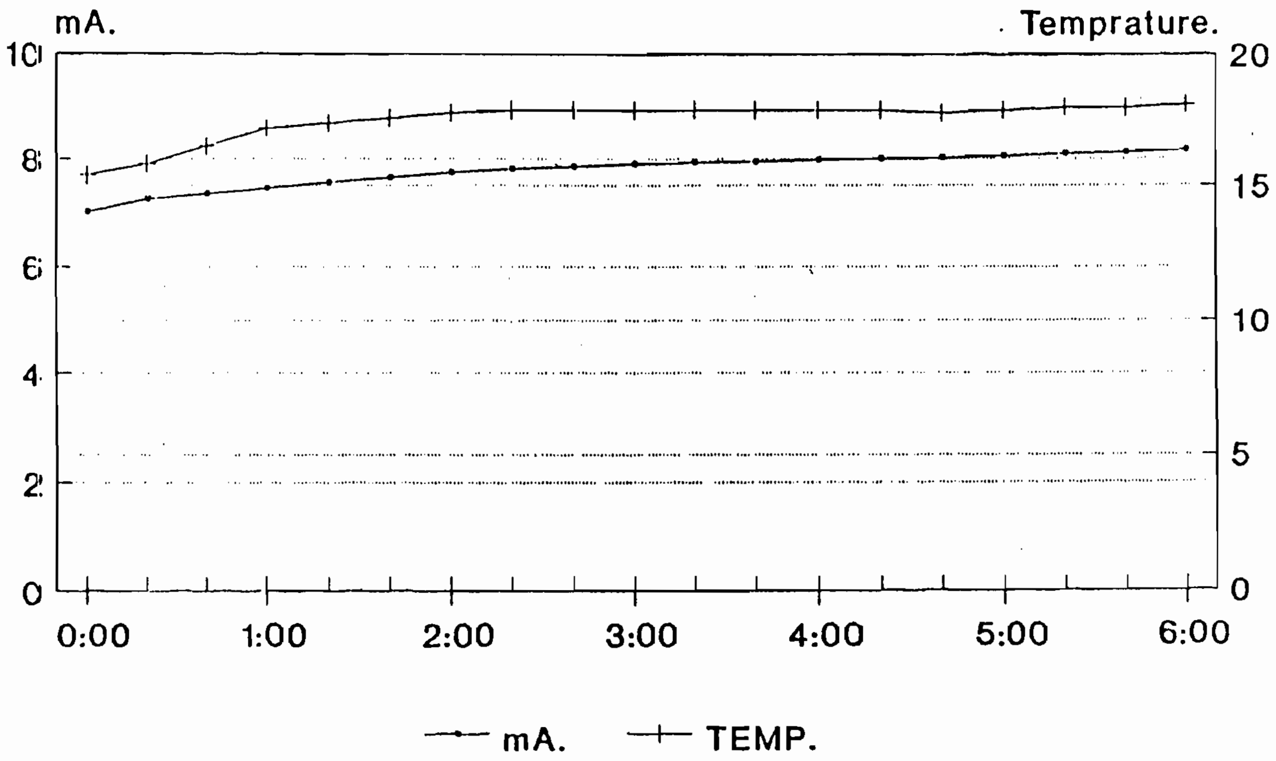


Figure 7 - Temperature and electrical conductance of the sample No. 04406-a

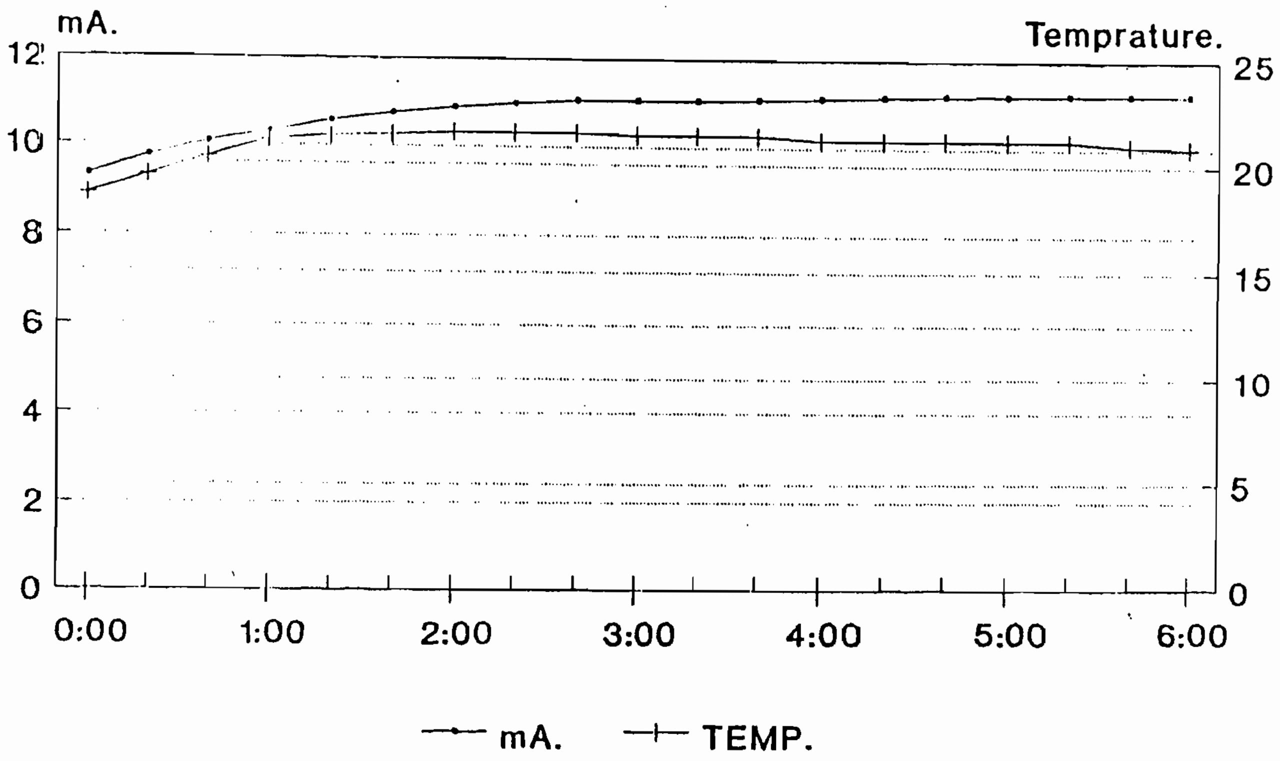


Figure 8 - Temperature and electrical conductance of the sample No. 04406-b

## Conclusions

The test results show that according to ASTM C1202:

- The chloride ion penetrability of the special concrete mixture (including Portland cement type II, suitable water-cement ratio, and micro-silicate) is in class very low.
- By the application of Penetron to this special concrete mixture, no significant difference is observed. It means by adding the Penetron, the chloride ion penetrability of the special concrete mixture remains always in class very low.
- Ordinary concrete mixture (used in port area outside Wharf) without micro-silicate nor Penetron shows high penetrability.
- By the application of Penetron to the ordinary concrete mixture (already used in port area outside Wharf), its penetrability to chloride ion reduces to classes low to very low.

So the resistibility of special concrete mixture including micro-silicate, Portland cement type II, and suitable water cement ratio to chloride ion penetration is well qualified and there is no need to additional protective such as Penetron.

In the other hand, application of Penetron to already constructed structures in areas with high corrosion risk, may reduce the chloride ion penetrability to classes low and very low.

## References

[1] ASTM C 1202 91, Standard test method for electrical indication of concrete's ability to resist chloride ion penetration, pp. 627-632.

ACI Manual of concrete practice (1984)

[2] Moskvin V., Ivanov F., Alekseyev S., Guzeyer E. (1983) Concrete and reinforced concrete deterioration and protection, translated from the Russian by Kolykhmatov V., Mir publishers. 399 pages.

## Abstract

In marine structures the existence of saline water and oxygen may cause problem. Also the warm climate of the region may increase the dissolved air in seawater. But a fundamental reason of the deterioration is the problem of concrete mixture and that is what has happened at the port of Imam-Khomeini in the nord of Persian Gulf in Iran.

To solve this problem, a concrete shotecrete mortar including Portland cement type II, water-cement ratio equal 0.4, and micro-silicate, with a compressive strength of $500 kg/cm^2$ is designed. In order to evaluate the impermeability of this concrete mixture, several concrete specimens, prepared at the port of Imam-Khomeini are prepared and tested.

This article is devided in two sections. In the first section, an apparatus that is constructed at Tafresh Campus of AmirKabir University of Technology is presented. The test procedure is according to A.S.T.M. C 1202-91. The test method consists of determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions.

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**خلاصهٔ مقاله: تخمین مقاومت بتن بندر امام خمینی در مقابل نفوذ یون کلرید**

آب شور و اکسیژن محلول در آب و هوا از عوامل مخرب سازه های دریایی هستند. هـوای گـرم نـیز بـه نوبـهٔ خود، با افزایش اکسیژن محلول در آب و هوا باعث تشدید خرابیها میشود. اما علت اصلی تخریـب سـازه هـای خمینی در بندر امام خمینی، نامناسب بودن طرح اولیهٔ مخلوط بتن است.

برای حل این مشکل، ملات شاتکریت با مشخصات: سیمان پرتلند نوع دو، نسبت آب بـه سـیمان برابـر ۰/۴، میکروسیلیکات، مقاومت فشاری ۵۰۰ کیلوگرم بر سانتیمترمربع طراحی گردید. سپس برای ارزیابی طرح مخلوط انجام شده، مراحل زیر انجام گرفت.

ابتدا دستگاهی مطابق با استاندارد ASTM C 1202-91 در مرکز پژوهشـــی دانشـگاه صنعـتی امیرکـبیر واحد تفرش ساخته و کارآیی آن امتحان گردید. عملکرد این دستگاه عبارت از تخمین هدایت الکتریکی بتن، به منظور شناسایی سریع مقاومت بتن در مقابل نفوذپذیری یون کلرید میباشد.

در دومین مرحله، چهار طرح گوناگون مخلوط بتن که در بندر امام خمینی نمونه برداری شـدند بـا یکدیگـر مقایسه گردیدند. نتایج متعددی حاصل گردید، از جمله آنکه طرح مخلوط بتـن بـا مشـخصات بـالا دارای نفوذپذیـری بسیار کمی در مقابل نفوذ یون کلرید میباشد.