# COMPARATIVE ANALYSIS OF POLYURETHANE AND EPOXY BASED SURFACE COATINGS ON THE DURABILITY OF CONCRETE

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**ABSTRACT**
Durability of concrete is an imperative parameter to consider while constructing a concrete structure. It is essentially the ability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. This is an important parameter to consider because during the last half of this century there has been a considerable increase in the amount of pollutants in the atmosphere due to rapid industrialization in developing countries like India and Sri Lanka. Therefore to increase the durability of concrete considerably at an affordable cost, hydrophobic materials are used as a surface coating to impede the permeability of undesirable effluents like water.Since surface coating itself is not immune to weathering action and chemical attack, it is proposed to study its effect on the durability of surface coated concrete subjected to artificially created conditions similar to environmental conditions. Tests on concrete and mortar samples evaluate the response of concrete under conditions like Initial Surface Absorption Test and Acid attack test. The parameters involved compares the Durability of concrete with polymer coating with variation in thickness of the coating as well as makes the comparison within the Durability characteristics of various polymers. The results obtained can be used in selection of materials depending upon the environmental conditions.

**Keywords**: Durability, Surface Coating, Concrete, Water Permeability,

## INTRODUCTION

Concrete is the second most extensively used composite in the world. The total production of cement (the major component of concrete) is about 4 billion tons yearly. Concrete structures are used for constructing buildings, towers, bridges, dams etc. Thus it has become imperative that these structures live up to the designed loads for their expected design life. Buildings are a part of the built environment. The built environment is constructed for a variety of purposes. The life envisaged for a structure will depend on its purpose and a broad threefold classification can be made.

(1) Monumental structures such as churches and temples would be expected to last for even a thousand years. A Hindu temple recently constructed in North London is supposed to have a design life of 1000 years; some churches that are in use today approach that sort of age.
(2) Service structures such as bridges and reservoirs would be expected to last for at least around 100 to 200 years.
(3) Sheltering structures such as offices and dwellings are rarely expected to last of rover 100 years. It is such structures, also called buildings that this report focuses on.

## REVIEW LITERATURE

Concrete has come to be known as an exceptionally efficient construction material over the better part of the last century. According to Swamy and Tanikawa (1993,p.465) It has an inherently high alkalinity and provided reasonable care and control are exercised in the choice of materials, and in the fabrication, placement, compaction and curing of the final product, concrete has provided a safe and protective alkaline environment to the steel embedded in it. There is extensive evidence to show that in many environments, concrete has very satisfactorily and serenely withstood the test of time, stress unforeseen loads and unfavorable human conditions. Paradoxically, while being intrinsically protective to steel, it is the same concrete material that permits and controls the ingress of destructive agents that slowly but steadily destroy the stability of the concrete itself. .

The protection of concrete surfaces has been a factor of immense importance since the use of concrete in construction projects. The failure of the concrete surface to protect for e.g. the steel reinforcement can lead to catastrophic failure on the long run; A Study by Roy et al. (1999) has shown that performance of concrete greatly varies due to its resistance to the elements.

The primary objective of this study is to augment the performance, indeed it is a commonly held belief that the deterioration of concrete structures due to environmental factors is determined almost entirely by the ability of the surface to keep out the harmful agents in the environment. One of the most important factors to consider when we talk of concrete deterioration is permeability of water; according to Poyet (2013,p.127) water significantly influences concrete behavior (for instance through shrinkage and creep that can result in cracking) and durability (through transport properties and inhibition of in-solution chemical reactions).

Swamy and Tanikawa (1993) state that the protection methods that are presently adopted include: (1) use of protective concrete surface coatings; (2) use of metallic, epoxy and polymeric coatings on the steel and (3) use of corrosion inhibitors. These measures are suitable for new and old buildings. The ability of a surface coating to protect old structures is commendable as it can protect existing buildings and even come in use to protect old heritage sites. Extensive studies have already been conducted to improve surface endurance, even though coated reinforcing bars are being used currently in construction. However, the usefulness of coated reinforcing bars as compared to surface coated concrete is still riddled by conflicting opinion and consensus is yet to be established about coated reinforcement bars.

Looking at surface Coatings, particularly coal tar, chlorinated rubber, epoxy, etc. have been applied on the footings and piers, to avoid concrete deterioration due to sulphate attack. However, concrete coatings of several generic types are now marketed for protecting concrete at both above and below ground levels. Dulaijan et al. (2000a) and Dulaijan et al. (2000b) evaluated the performance of cement and epoxy based coatings in protecting concrete. Results of that study indicated that epoxy modified cement based coatings provide adequate protection to concrete. However, the crack bridging capacity of the polymer Modified cement coating was reported to be better than that of other cement-based coatings. (Dulaijan et al. ,2000b) The adhesion of all the epoxy resin-based coatings, to the concrete substrate, was noted to be better than that of the acrylic resin-based surface coatings. The water permeability in the concrete samples coated with the selected resin based surface coatings was reported to be very low and they exhibited good crack bridging ability. Further, all the coatings were noted to considerably reduce the diffusion of carbon dioxide into the concrete matrix. However, not all the coatings were able to withstand acidic exposure. According to Dulaijan et al. (2000b) the chemical-resistance of epoxy resin based surface coatings was shown to be better than that of acrylic resin-based coatings.

Swamy and Tanikawa (1994) evaluated the effect of surface coatings to preserve concrete durability and concluded that the application of an impervious surface coating to concrete is a very attractive solution to protect new and existing concrete structures. Sergi et al. (1990) studied the influence of surface treatments on corrosion rates of steel in carbonated concrete and concluded that water-repellant surface treatments that line the pores of concrete with hydrophobic layers, were effective in resisting water penetration and limiting the corrosion rate of steel in carbonated regions in the samples exposed to cycles of wetting and drying. Basheer and long (1997) presented a useful summary on the related studies and the techniques utilized to evaluate the performance of surface coatings.

With encouraging reports on the performance of concrete surface coatings, a wide range of these, representing different generic types, are now available in the market. Under these circumstances, selection of a surface coating is all the more difficult, particularly in the absence of performance data. This study is conducted to evaluate the performance of generic types of concrete surface coatings that are available in the market, polyurethane and epoxy. The objective is also to assess the performance differential between these two coatings representing similar generic types.

## EXPERIMENTAL PREPARATION

### Experimental Preparation

### Material Composition and Preparation

Cement meeting the standard IS 1489-1 also known as the Pozzolana Portland cement is used for this study.

Table 1. IS 1489-1 Portland Pozzolana Cement Chemical Composition

| Chemical Constituent | Weight (%) |
|---|---|
| SiO | 46.25 |
| $Al_2O_3$ | 17.34 |
| $Fe_2O_3$ | 10.26 |
| CaO | 10.18 |
| MgO | 2.90 |
| $K_2O$ | 1.64 |
| $Na_2O$ | 3.64 |
| $SO_3$ | 0.8 |
| Cl- | 0.01 |

The ratios in which the cement, fine aggregate and coarse aggregate mixed were 1:1.8:3.3 respectively. Three batches were made consisting of 12, 12 and 6 samples. The material required for each batch is given in Table 2.

Table 2. Material required for each batch

| | |
|---|---|
| Cement | 17.52 Kg |
| Fine Aggregate | 30.73 Kg |
| Coarse Aggregate | 57.94 Kg |
| Water | 8.8 Liters |

### Test Samples

Concrete was filled into the cube moulds in layers approximately 5 cm deep. The components of the sample when placed in the mould were compacted by a Vibrating table operating at a frequency of 10 Hz. The samples were also compacted using a Tamping Rod as per IS:10086-1982, the tamping rod is 600 mm long and has 16 mm rounded working end which is made of mild steel. The open end of the mould was inspected to make sure that the shape remained consistent and was left to harden for 24 hours. The samples were then de-molded and placed in the curing tank for a period of 28 days with the pH of water in the tank being kept at 6.7.

15 samples of size 100x100x100 $mm^3$ and 15 samples of size 150x150x150$mm^3$ were both prepared according to IS:10086-1982. The 150x150x150 $mm^3$ samples were cast to perform the Water permeability test and the 100x100x100 $mm^3$ samples were cast to evaluate chemical resistance.

After the surface preparation and coating was complete the Samples for the water permeability test were placed in the oven for approximately 48 hours at 75 degrees centigrade until a reduction in mass of 0.01 percent was achieved. Then the samples were kept in the desiccator for 12 hours at 25 degrees centigrade.

**Surface Preparation**

After curing and significant drying, the surface of the samples were coated with a polyurethane based putty to clear any voids in the surface and to provide a proper bonding surface between the coating and the concrete. The samples were then left to dry according to the manufacturers specifications. The surfaces were then manually sand papered using ISO/FEPA Grid designation P100 sized sand paper until the surface was noticeably smooth.

**Coatings used and Coating methodology**

Coatings used are of the type

Polyurethane Surfacer, PU

1. Epoxy Based Zinc Phosphate primer, EP

The coatings were applied according to the coating manufacturer's instructions to a thickness of 60μm for 12 samples and 120μm for 12 samples for both respective sizes. The thickness of the coating is achieved by adjusting pressure ratio of the air cylinder to hydraulic cylinder in accordance with the viscosity of the material to be sprayed.

The standard specifies a drying time of minimum 20 minutes, with a Dry Film Thickness of minimum of 60μm and the theoretical spreading capacity of 8 Square meter /liter.

## TEST PROCEDURE

### Water Permeability Test

The water permeability Test conducted was the ISAT (Initial Surface Absorption Test). The ISAT test was carried in accordance with the standard provided by BS 1881 part 5. Samples measuring 150x150x150 $mm^3$ of which 6 PU, 6EP and 3 uncoated samples were used. It should be noted that for this test the samples were oven dried and desiccated.

The test consists of the measurement of water flow into the test sample through a known surface area. The contact area is defined by a plastic cell sealed onto the surface. Measurement of the volume flow is obtained by measurement of the length of flow along a capillary of known dimensions. The test assembly comprises of a watertight cap which is sealed to the concrete surface and connected by means of flexible tubes to a reservoir and a capillary tube with a scale. A control tap is fitted between the reservoir and the cap.

Before use, the capillary tube is calibrated to determine the area of the cross section. The area of the cell is measured and the scale factor for the cell/tube combination is determined. This came out to be;

0.01 ml/m$^3$/sec = 6x10$^{-4}$ Area $_{cell}$ length mm of tubing Area $_{capillary}$

The Test begins by attaching the cap from the test rig on to the test surface and slightly greasing the gasket before attaching it. The cap is clamped to the test surface so as to ensure an even pressure and good seal around the perimeter. If necessary the seal is improved with silicone sealant, 'Plasticine™' or 'Blu-tack™'. The capillary tube and reservoir are mounted 200mm above the cell. The cap has an inlet and an outlet which lets water run along the surface with a head of 180 mm to 220 mm.

The inlet is connected to a reservoir of 100mm diameter of which the level of water is to be kept constant throughout the test. The outlet is connected to a horizontally placed capillary tube of which the head should be as same as that of the reservoir. The capillary was of precision bore glass capillary tubing of 200 mm length and with a bore of 0.4 mm radius and was attached to a scale. The Reading begins by opening the reservoir and starting the stop watch. The readings are taken at intervals of 10, 20 and 30 minutes for each sample with the drop in capillary water seeping back into the concrete measured for 60 seconds and the respective intervals. The measurements are only taken after closing the reservoir valve. The drop in meniscus along the horizontal capillary tube is measured and plotted.

### Chemical Resistance Test

Samples with dimensions 100x100x100 mm3 were used for this test. A sulphuric acid solution 2.5% strong was used to test the samples. The samples were coated on all sides and were kept in the acid bath.

The samples were visually inspected at regular intervals. The evaluation was based on a qualitative measure of the surface ranging from 1 to 5; 1 would indicate no deterioration and 5 would indicate complete deterioration of the coating.

## RESULTS AND DISCUSSION

The samples are abbreviated as:
UC: Uncoated Samples, EP1: Epoxy at 60µ, EP2: Epoxy at 120µ, PU1: Polyurethane at 60µ, PU2: Polyurethane at 120µ

### Water Permeability

Table 3. ISAT Test Results

| Type of sample | Sample | Reading at 10 | Reading at 30 | Reading at 60 |
|---|---|---|---|---|
| For Uncoated Samples (UC) | 1 | 23.5 | 12 | 6.4 |
| | 2 | 23.8 | 12.2 | 6.8 |
| | 3 | 23.5 | 11.8 | 6.6 |
| For Epoxy Coating (at 60µm) (EP1) | 1 | 0.9 | 0.53 | 0.45 |
| | 2 | 1.2 | 0.65 | 0.5 |
| | 3 | 1.1 | 0.65 | 0.45 |
| For Epoxy Coating (at 120µm) (EP2) | 1 | 0.6 | 0.2 | 0.12 |
| | 2 | 0.7 | 0.24 | 0.18 |
| | 3 | 0.7 | 0.2 | 0.16 |
| For Polyurethane Coating (at 60µm) (PU1) | 1 | 1 | 0.4 | 0.3 |
| | 2 | 0.9 | 0.5 | 0.3 |
| | 3 | 1.1 | 0.5 | 0.3 |
| For Polyurethane Coating (at 120µm) (PU2) | 1 | 0.5 | 0.16 | 0.1 |
| | 2 | 0.7 | 0.2 | 0.1 |
| | 3 | 0.5 | 0.23 | 0.2 |

The results are obtained after closing the reservoir valve, and the measurement is taken from the point the meniscus appears at the reference mark to the point to which it moves in one minute. These readings are taken after 10, 30 and 60 minute intervals and these values are shown in above Table 3.

Further, taking an arithmetic mean of the values, the table depicts the variation of readings for different coatings as follows:

Table 4. Average values for the ISAT Test Results

| Coating Type | Reading at 10 minutes in mm | Reading at 30 minutes in mm | Reading at 60 minutes in mm |
|---|---|---|---|
| UC | 23.6 | 12 | 6.6 |
| EP1 | 1.06 | 0.61 | 0.46 |
| EP2 | 0.67 | 0.21 | 0.15 |
| PU1 | 1 | 0.46 | 0.3 |
| PU2 | 0.56 | 0.19 | 0.13 |

The Value obtained in Table 4 only shows us the capillary scale reading, therefore the rate of water absorbed is calculated using the spacing ratio after the calibration of apparatus, the spacing ratio comes out to be,

$$1.15 \quad mm = 0.01\ ml/\ m^3/s$$

So, accordingly, the table after considering the spacing ratio is given by Table 5.

Table 5. Average ISAT Test Results Considering the spacing Ratios

| Coating Type | Reading at 10 minutes ($ml/m^3/s$) | Reading at 30 minutes ($ml/m^3/s$) | Reading at 60 minutes ($ml/m^3/s$) |
|---|---|---|---|
| UC | 0.749 | 0.38 | 0.209 |
| EP1 | 0.033 | 0.019 | 0.014 |
| EP2 | 0.021 | 0.006 | 0.004 |
| PU1 | 0.031 | 0.014 | 0.009 |
| PU2 | 0.017 | 0.006 | 0.004 |

It was noted that for the uncoated sample the absorption was significantly large compared to that of the coated sample. But for the coated samples the absorption was considerably small. The results are better elaborated of which figure 1, as it is evident the difference between coated and uncoated cement mortar sample. As the permeability of the uncoated samples was established from the results, the permeability of the coated samples is better elaborated by omitting the uncoated sample from figure 1 and thus the better illustrating it in figure 2. As the graph indicates the permeability of Polyurethane coated samples is better than that of the Epoxy coated sample. Polyurethane 120 µm coating performs especially well as compared to the 120 µm Epoxy coating.

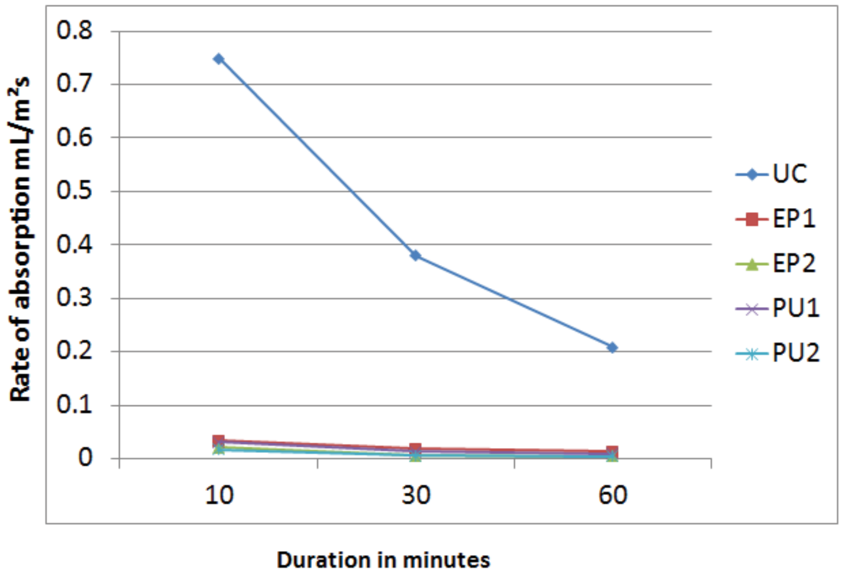


Figure 2. Rate of Absorption against duration

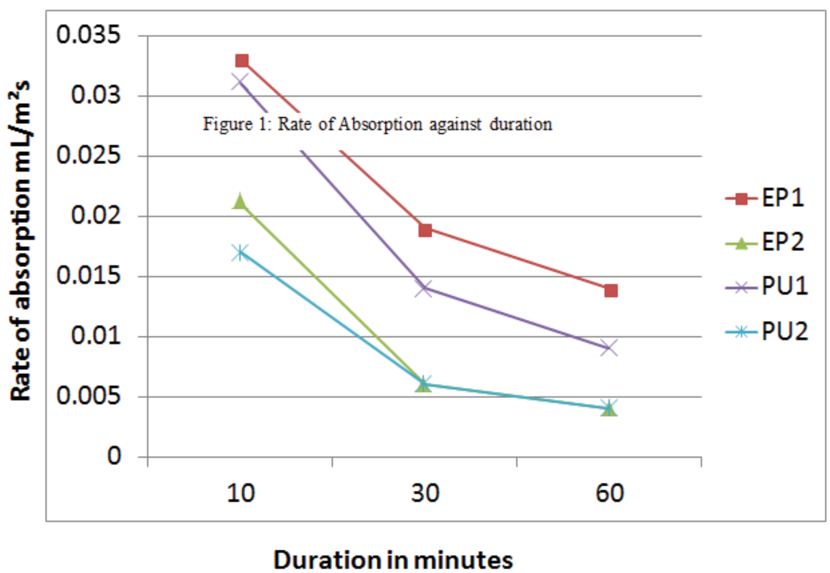


Figure 3: Rate of Absorption against duration omitting the UC Sample

Therefore, based on the results the performances of the coatings are on the following descending order

1. Polyurethane, PU2
2. Epoxy, EP2
3. Polyurethane, PU1
4. Epoxy, EP1

**Chemical Resistance**

The chemical resistance test can be depicted by showing the deterioration of different coatings over a period of time (every 24 hours till 120 hours). The Results obtained are represented in the Table 5.

Table 5: Rating after 120 hours

| | RATING | | | | | |
|---|---|---|---|---|---|---|
| Sample | Initial | 24 hours | 48 hours | 72 hours | 96 hours | 120 hours |
| PU2 | 1 | 1 | 1 | 1 | 1 | 1 |
| PU1 | 1 | 1 | 1 | 1 | 1 | 1 |
| EP2 | 1 | 1 | 1 | 1 | 1 | 1 |
| EP1 | 1 | 1 | 1 | 1 | 1 | 1 |
| UC | 1 | 2 | 3 | 4 | 5 | 5 |

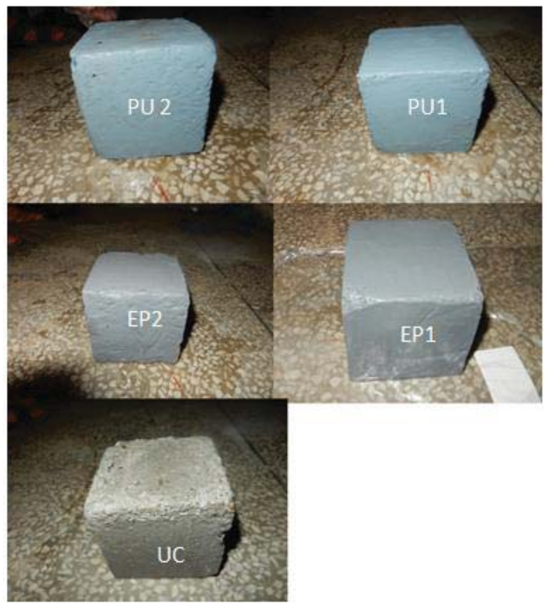


Figure 3. Samples after 120 hours in the acid bath

The samples were submerged in the acid bath containing 2.5 percent sulphuric acid. The polyurethane and epoxy coated samples both exhibited good resistance, even though the edges did show minimal signs of deterioration but insignificant to take it into consideration. However the uncoated samples started showing signs of deterioration after just 12 hours in the acid bath. The performances of the coated samples are relatively same for the test conducted.

## CONCLUSION

Polyurethane and epoxy coated samples performed equally well for the ISAT test at 60 and 120 µms respectively. The polyurethane however had a slightly lower affinity towards the absorption of water for both 60 and 120 µms.

The same case prevailed for the acid test containing 2.5% sulphuric acid as polyurethane and epoxy coated samples did not show any signs of deterioration after 120 hours in the acid bath.

The uncoated samples for both the tests demonstrated what the absence of such a coating would result in as the in the case of the chemical resistance test the sample deteriorated significantly.

## RECOMMENDATIONS

Since the chemical resistance test did not explicitly determine the durability of the coatings, the recommendations are based on the ISAT test and the cost for coating the samples. Table 6 gives the costs per unit area of coating.

Table 6:

| Coating | Cost in INR/m² |
|---|---|
| Polyurethane 60µm | 25 |
| Epoxy 60µm | 22.5 |
| Polyurethane 120µm | 50 |
| Epoxy 120µm | 45 |

(Note: INR refers to Indian rupees)

Therefore based on the results the recommendations can be

1. The rank of material for ISAT are PU2>EP2>P1U>EP1>UC; it means that Polyurethane (120µ) is the best suited material for providing water impermeability.

2. The rank of material based on the cost are UC>EP1>PU1>EP2>PU2; it means that uncoated sample is the best preferred sample because it involves no extra cost. But, if the use of coating is imperative, then Epoxy at 60µ is the best option.

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