Waterproofing of primary lining in tunnel using nano chemicals and soil modifiers in Concrete.

Ubaid Ali Parray, Harpreet Singh
Department of Civil Engineering Chandigarh University

Abstract: The use of waterproofing chemicals in the field of concrete technology has proven a significant boom in the civil engineering industry by increasing the life of concrete structures. The materials such as nano-acrylic polymers resulted, significant control over the water leakage and damping conditions especially Terrasil and Zycobond and various nano sealers such as Zycoprim+ and Zycosil+. In this study, the primary focus is to waterproof tunnels using the various acrylic, nano-technological, and soil modifier chemicals to stabilize the tunnel structure in areas of hilly terrain. The use of these chemicals has been sourced in other areas of application but the least glance is seen in the field of tunnel engineering. These chemicals bind with the concrete and form a hydrophobic layer thus decreasing the permeability of concrete structure. In the present study the percentage of Zycobond and Terrasil used was 1.5% by weight of concrete and the ratio for Zs+:Zp+:water was 1:2:20. Tunnels especially in hilly terrain pass the flowing streams, thus making it more prone to damping conditions. So, poor site conditions result in less durability of concrete as well as steel, therefore improvement in engineering properties using these chemicals is primarily sought out in this paper. The factors considered during the use were the permeability, strength, volumetric analysis of chemicals, material properties etc. Water-proofing the concrete improves various engineering properties such as permeability, compressive strength, durability, strength, and various other properties of Concrete.

Key-Words:- Zycosil+, Zycoprim+, Zycobond, Terrasil, Waterproofing of concrete, Strength, etc.

Objective: - To check the viability of Zycosil+ and Zycoprim+, Terrasil and Zycobond as waterproofing agents in concrete.
1. Introduction

In the past decade, the developmental boom in the field of construction especially in the field of transportation and building construction has sought the intention of engineers and researchers significantly. The rise in development also resulted in the exploration of new arenas and waterproofing being the advanced version of it. As the durability of concrete decreases with damping conditions [1–4], hence many efforts have been put forth for overcoming this problem. The tunnel waterproofing in hilly terrain is the least area explored due to topographical features of India and also the least scope of work. Many attempts put forth in the overcoming of such problem are framed out to prevent the concrete scaling and preferably the steel in RCC structures. The different types of concrete waterproofing techniques are:

- Cementitious Waterproofing.
- Waterproofing Membrane (Liquid).
- Bituminous Coating.
- Bituminous Membrane.
- Admixtures.
- Crystalline Admixtures.
- Nano-technology acrylic Sealers.

Among all these nano-sealers are the best in the way that bond up with the siliceous material and form a better bond to seal even minor cracks, thus it is a diversity zone to be explored in the field of research. Terrasil is a reflex soil modifier that lastingly modifies the soil façade, making it hydrophobic. Zycobond being the dust reducer and significantly works with terrasil providing a waterproof membrane. These organic sealers bind with siliceous material present in cement and become an integral part of concrete by converting siliceous surface water-loving silanol groups to water repelling alkyl siloxane groups. The reactive mechanism of the chemicals when concrete is treated is given by the reaction as under [5,6]:

\[
\text{Si} \text{-OH} + \text{OH} \text{-Si} \text{-R} \rightarrow \text{Si} \text{-O} \text{-Si} \text{-R (alkyl)} + \text{H}_2\text{O (Evaporate).}
\]

Zycosil+ is a nano sealer that seals the concrete at micro-pore level, due to its reactive nature it bonds with concrete easily. It is an organosilane containing silanol group that makes it dissolution easy in water. It penetrates up to 2mm deep in substrate and forms a bond with structure.

Zycoprime+ acts as primer for Zycosil+ and acts as bonding agent in liquid consistency. It is acrylic co-polymer emulsion.

The area of the application is different somehow in a way that it is to be enforced in the tunnels while shotcreting, also the tunnel construction involves excavating the soil which is preferably rich in siliceous materials, so the implication of such materials will benefit society. The method of application involves two processes which can either be mixed with concrete or sprayed with the help of spray nozzle, but keeping the economical considerations in mind mixing it with concrete involves less wastage than spraying. So, mixing method is put forth in the experimental setup. The whole setup was examined at 1.5% of zycobond and 1.5% of terrasil by volume of concrete to checks its viability.

Nano-sealers and soil modifiers became an integral part of concrete so there is no need of changing the previously used geo-membranes as they wear out due to abrasion and hence result in leakage of concrete lining in tunnels, thus resulting in the deterioration of tunnel surface.
2. MATERIALS AND EXPERIMENTAL PROCEDURE:

2.1 Material

Aggregates:

Crushed siliceous and argillaceous aggregates were collected from dumping yard of Chandigarh University. The gradation of these aggregates was done on the basis of IS 383 (1970) with the help of sieve shaker, see table 1.

Table 1: Physical Properties of Aggregates

| S.NO | Property                          | Result (%) | Test Code          |
|------|----------------------------------|------------|--------------------|
| 1.   | Specific Gravity of coarse aggregates | 2.69       | IS:2386 Part 3     |
| 2.   | Water absorption of coarse aggregates | 0.8        | IS:2386 Part 3     |
| 3.   | Specific Gravity of fine aggregates | 2.50       | IS:2386 Part 3     |
| 4.   | Water absorption of fine aggregates | 1.49       | IS:2386 Part 3     |
| 5.   | Elongation and flakiness Index    | 26.75      | IS:2386 Part 1     |

2.2 Cement:

The cement used in the study was obtained from local dealer in Kharar. The grade of cement used in the study was OPC-53 conforming to IS:169-1989. See table 2.

Table 2: Physical Properties of Cement

| S.NO | Property       | Result | Test Code          |
|------|----------------|--------|--------------------|
| 1.   | Specific Gravity | 3.12   | IS:169-1989        |
| 2.   | Normal Consistency | 31%    | IS:169-1989        |
| 3.   | Initial Setting Time | 60 min | IS:169-1989        |
| 4.   | Final Setting Time   | 350 min | IS:169-1989        |

2.3 Zycobond and Terrasil:

Zycobond and Terrasil are UV and heat stable reactive soil modifiers which on reacting forms a cross-linkage with the surface, hence waterproof suitable materials.

For the current study these nano chemicals were obtained from the nearby site in Qazigund area of Anantnag from Unique Construction Company, see table 3 and 4.

Table 3: Physical Properties of Zycobond

| S.NO | Property        | Result          |
|------|----------------|-----------------|
| 1.   | Form            | Liquid          |
| 2.   | Colour          | Milky White     |
| 3.   | Viscosity       | 10-100 cps      |
| 4.   | Specific Gravity| 1.02            |

Table 4: Physical Properties of Terrasil

| S.NO | Property | Result  |
|------|----------|---------|
| 1.   | Form     | Liquid  |
| 2.   | Colour   | Pale Yellow |
2.4 Zycosil+ and Zycoprim+:  
Zycosil+ and Zycoprim+ are nano-acrylic waterproofing agents. These chemicals were collected from Haryana Steel and Iron works, Manimajra Chandigarh, see table 5 and 6.

Table 5: Physical Properties of Zycosil+

| S.NO | Property     | Result            |
|------|--------------|-------------------|
| 1.   | Form         | Liquid.           |
| 2.   | Colour       | Light Pale Yellow |
| 3.   | Viscosity    | 500 cps           |
| 4.   | Specific Gravity | 0.91 ± 0.01     |

Table 6: Physical Properties of Zycoprim+

| S.NO | Property     | Result     |
|------|--------------|------------|
| 1.   | Form         | Liquid.    |
| 2.   | Colour       | White      |
| 3.   | Viscosity    | 500 cps    |
| 4.   | Specific Gravity | 1.01-1.02 |

3. Methodology:

The whole testing was done on M25 grade of concrete with water-cement ratio as 0.5 as the primary lining of tunnel uses M25 grade of concrete and the methodology followed is given below:

3.1 By Volumetric Analysis:

Zycosil+ and Zycoprim+ were diluted with water, first 25ml of Zycosil + was added with 500ml of water after stirring it completely 50ml of Zycoprim+ was added. Thus, making a solution of 575ml and was sprayed over the cube in three layers, see figure 1.
3.2 **By Weight Analysis:**

Terrasil was first diluted in water and then Zycobond was added to the solution, the entire solution was then added by weight of concrete, the percentage added was 1.5% each of Terrasil and Zycobond [7,8], see figure 2.

3.3 **Mix Design of Concrete:**

The design mix for M25 grade of concrete was prepared in consonance with IS 456:2000 and IS 10262:2009. The main objective was to design economical mix. The cubes were casted in 150*150 mm moulds and filled with tamping rod in three layers 20-25 tamps/layer. The air voids were removed using automatic cube vibrating machine [9–11].

4. **Results and Discussion:**
4.1 Compressive Strength Test (IS:516-1959):

The cubes for Compressive strength test were casted according to the IS standards with dimensions as 150*150*150mm. The specimens were treated with two different combination of chemicals with Zycobond and Terrasil as 1.5% each by weight of concrete, zycosil+ and zycoprim+ in the ratio of 1:2 parts diluted in 20 parts of water [12–14], see table 7.

These results were obtained on 27 specimens of concrete are given in the table (a):

| S.NO | Concrete Type                        | Average Compressive Strength In N/mm² |
|------|--------------------------------------|--------------------------------------|
|      |                                       | 7 days | 14 days  | 28 days  |
| 1.   | Normal                               | 19.63  | 27.37    | 29.64    |
| 2.   | Addition of Zycosil+ and Zycoprim+   | 21.06  | 28.23    | 31.44    |
| 3.   | Addition of Zycobond and Terrasil    | 17.82  | 25.07    | 27.42    |

The casted cubes were checked for compressive strength as per the IS 516:1959 after 7, 14 and 28 days. The graph for compressive strength vs. time is given in Fig 3:

Figure 3: Compressive Strength vs. Time
4.2 Permeability Test (IS:3085-1965):

The permeability test was carried according to the IS 3085:1965 with cell dimension as 170 mm. The casted cubes were tested after 28 days with dimensions as 150*150*150 mm. The pressure head maintained was 7.5 kg/cm² for plain concrete and 15 kg/cm² for chemically treated cubes. The flow values were checked after 4 days. See table 8 and figure 4.

Table 8: The result in the variation in coefficients of Permeability

| S.NO | Normal Concrete | Addition of Zycosil+ and Zycoprime + | Addition of Zycobond and Terrasil |
|------|----------------|--------------------------------------|----------------------------------|
| 1    | 1.43×10⁻¹⁴     | 2.63×10⁻¹⁶                          | 1.21×10⁻¹⁴                       |

Figure 4: The graphical variation in permeability for different specimen of concrete.

4.3 Rilem Test (Test No II.4):

Rilem test was conducted in order to calculate water absorbed by the plain and chemically treated concrete. This test was conducted according to RILEM Test No II.4, see table 9 and figure 5.

Table 9: The variation of water absorption and time.

| S.NO | Time In (Minutes) | Water Absorbed in ml |
|------|-------------------|----------------------|
|      |                   | Normal Concrete      | Addition of Zycosil+ and Zycoprime + in Concrete | Addition of Zycobond and Terrasil in concrete. |
Table 1: Water Absorption Data

|   | Water Absorbed (ml) | Time (min) |
|---|---------------------|------------|
| 1 | 0.3 ml              | 5          |
| 2 | 0.85 ml             | 10         |
| 3 | 0.92 ml             | 15         |
| 4 | 0.81 ml             | 20         |
| 5 | 0.8 ml              | 25         |
| 6 | 0.9 ml              | 30         |
| 7 | 2.1 ml              | 60         |

Figure 5: The graph for Water Absorption vs. Time

5. Conclusion:

Tunnel construction is a slow process which needs proper supervision and quality control. The use of geo-membranes or geo-textiles as frames gets torn due to excessive wear and tear due to rock surface which leads to leakage in tunnel surface and abruptly this water falls to the roadway in tunnel. This not only results in deterioration of tunnel crown but also the surface of road leading to the closure of tunnel. So in order to prevent the frequent breakdown nano-sealers and soil modifiers are somewhat technically feasible materials of avoiding such a problem, it will not only save time but also the renovation process, as the results are enough to be used in field.

In context to the above literature, the material is tested for siliceous surface only i.e. Soil and this literature is enough that these chemicals are to be used in the waterproofing. The addition of a combined phase of terrasil and zycobond significantly resulted in waterproofing but further investigations in the research are to be put forth before examining it on the field.

- The compressive strength as observed in case of Zycosil+ and Zycoprim+ showed a significant increase hence suitable in tunnel lining in contrast to conventional concrete. This
is due to the fact that Zycoprim+ acts as bonder and seals the surface and joins it, thus increase in strength is factually possible.

- It has been observed there is slight decrease in compressive strength as in case of Zycobond and Terrasil mixed concrete, hence an area of concern to be looked in terms of strength. The test materials are used in soil sub-base and the percentage chosen is random.

- Permeability decreased by 15% in case of Zycobond and terrasil and 98% in Zycosil+ and Zycoprim+ treated concrete in comparison to normal concrete. The results are quite satisfactory in relevance to the available literature review.

There is significant decrease in water absorption in contrast to normal concrete, thus signifying waterproof characteristics and the materials are logically sound for use.

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