The Scientific Temper (2023) Vol. 14 (4): 1381-1386
E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2023.14.4.47
https://scientifictemper.com/
RESEARCH ARTICLE

# Optimizing durability of the thin white topping applying Taguchi method using desirability function

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## Abstract

White topping is a relatively new rehabilitation technology for giving strength to Asphalt pavement. Time to time resurfacing is necessary for bituminous pavement in hot climate region of India where heavy vehicles, operating under frequent start/stop conditions. So, we can apply white topping where recurring problem arises due to rutting of bituminous pavement. In India, endeavors to develop both traditional and ultra-thin white toppings as well as thin white toppings were built on an experimental basis, but their outcomes have not been specifically tracked. The performance and existence of pavement is affected by a range of things such as the load imposed by means of the site visitors plying on it, the weather, indigenous materials used and renovation standards. To examine their overall performance below Indian site visitors and climatic conditions road roughness test, compressive power by way of taking concrete cores and visible inspection survey has been executed.

Moreover, the necessity for the new sorts of concrete with higher durability and higher overall performance for precise purposes, as compared to the available sorts, is sensed greater than ever. The concrete durability, laid low with one kind of variables consisting of compressive strength, resistance and permeability, has already attracted the attention of many researchers. In this research the effects of adding white topping concrete, changes in the humidity and temperature of the rehabilitated surrounding atmosphere are investigated to observe whether they will cause any growth in compressive strength and resistance of concrete and/or any decay in its permeability. For this, the Taguchi method is carried out as a method of design of experiment to get the most excellent level for every variable, accompanied by applying the regression approach to model the variables. finally, the final most desirable degrees for the sturdiness are offered primarily based on the desirability function.

**Keywords:** White topping, Compressive strength, Permeability, Taguchi method, Desirability function.

## Introduction

A bituminous road is covered with a Portland cement concrete (PCC) overlay known as white topping. Long-term restoration or structural strengthening of roadways may be replaced with this overlay. Traffic on the roads is progressively increasing over time, which is a global phenomena. According to a worldwide prediction, this surge will continue. There is a shortage of capital for new infrastructure projects everywhere, even the most developed countries. This is true for both their initial creation and, more importantly, their ongoing maintenance and repair. Increasing vehicle weights and tire pressures on our pavements have raised the requirement for pavement performance in recent years. As a consequence, more and more roads are degrading, and it is often determined that the current pavement structure as a whole is unable to keep up with the present. The importance of this huge community's development and restoration using a traditional manner would need enormous resources, both physical and financial, which may be relatively rare. Most resilient pavements on the grid consist of thin layers of bitumen. Increasing vehicle weights and tire pressures on our sidewalks in recent years have put pressure on the overall performance of our sidewalks. Most cracked asphalt roads may be traced back to longitudinal cracking. White layer (WT) cement concrete may be applied over an asphalt

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**How to cite this article:** Akshay, J., Kumar, G.M., Manjunath, B.H. (2023). Optimizing durability of the thin white topping applying Taguchi method using desirability function. The Scientific Temper, **14**(4):1381-1386.

Doi: 10.58414/SCIENTIFICTEMPER.2023.14.4.47

**Source of support:** Nil

**Conflict of interest:** None.



**Received:** 12/10/2023 **Accepted:** 17/11/2023 **Published** : 27/12/2023

surface to solve this issue. Thin white topping (TWT) and ultra-thin white topping (UTWT) are more popular than ever before, even more so than regular white topping. Most of the time, the bituminous pavements seen at intersections and other high-traffic areas deteriorate with time.

The majority of our roadways typically have the following flaws:

- Block crack (D-cracking)
- Rutting
- Fatigue cracking

Putting a white Topping (WT), made of concrete and cement, on top of an asphalt pavement may prevent thermal cracking (Naidu & Ramesh, 2020).

## Effective Factor for Durability

*Factors for effective response variables*

Curing performs a vital role on power improvement and sturdiness of concrete. It is also a key player in mitigating cracks inside the concrete, which critically influences sturdiness. The curing period depends on the ambient situations, i.e., the temperature and relative humidity of the encompassing surroundings (Cement Concrete & Aggregates Australia, Curing of Concrete-DATA sheet, 2006; Shetty & Jain, 2019). The present work studies the impact of temperature and relative humidity of the surrounding on the durability of the high-performance white toping.

*Humidity of the preserved surrounding atmosphere*

To examine the humidity of the curing two different surrounding atmospheres, particularly, the laboratory and the construction site, have been decided on. For the lab test a water pool (1st level) was used for submerging of concrete samples, and for the development of the construction site test (2nd level) the concrete samples had been wrapped in cotton to be splashed with water three times a day for the first three days and kept in cotton without water in the following days. Table 1 shows the levels of humidity of the preserved surrounding atmosphere.

*Temperature of the preserved surrounding atmosphere*

The surrounding temperature is the major element in concrete preservation. The boom inside the environment temperature affects in faster hydration. Within the recent study, three ranges of temperature were adopted to preserve the samples.

**Table 1:** Temperature and Humidity level of the preserving surrounding atmosphere

| *Temperature level* | | | *Humidity level* | | |
|---|---|---|---|---|---|
| *Level* | *Name* | *Code* | *Level* | *Name* | *Code* |
| 1 | 10–20°C | 15 | 1 | water pool | 1 |
| 2 | 20–25°C | 22.5 | 2 | water splash | 1 |
| 3 | 25–35°C | 30 | | | |

- The low temperature (10–20°C) means a slow concrete improvement at the 1st level.
- The standard lab temperature (20–25°C) for preserving the concrete improvement at the 2nd level.
- High range of temperature (25–35°C) for faster concrete improvement at the 3rd level.

Table 1 indicates the level of the temperature of the preserving surrounding atmosphere and Figure 1 indicates the implementing method for durability experiments.

*Selection for effective variables on durability*

Based totally on the carried-out investigations of concrete durability, it seems that concrete sturdiness isn't always immediately measurable, so to estimate it not directly, one or extra variables that can replicate the feature must be selected; consequently, 3 variables of compressive strength electric resistance and permeability have been decided on to evaluate durability:

- Compressive strength is measured according to the BS EN12390-3:2002 standard (Testing Hardened Concrete—Part 3, 2019).
- Resistance, may be measured by applying a current using two electrodes connected to the ends of a uniform cross-section specimen. Electric resistivity found from the Eq. (1) (McCarter *et al.*, 2009):

$$R = \rho \frac{l}{A} \qquad (1)$$

Where R is the resistance of the specimen, $\rho$ is the ratio of voltage to current in ohms, $l$ is the length of a specimen in meter, $A$ is the cross-sectional area of the specimen in $m^2$.

- Permeability: To a significant part, the pore system's penetrability determines how well concrete performs when exposed to a variety of hostile conditions. The water or other fluid penetration rate into unsaturated concrete is mostly managed by absorption due to capillary expansion based solely on ASTM regulations (Standard, 2011). These experiments evaluate the depth of water penetration under stress in hardened concrete following the guidelines in BS EN12390-8:2009 (Muthukumar *et al.*, 2003).

## Taguchi Technique

On account that the use of design of experiments (DoE), which may be specially categorized as complete factorial and fractional factorial design, was installed, it has been carried out in many diverse research inclusive of mineral aggregates (Sullivan, 2004), excessive power concrete beams (Panzera *et al.*, 2008), and aerostatic bearings (Phadke, 1989). Regarding the truth that the experiments are expensive and take too much time and that they contain complex calculations derived from full factorial and fractional factorial layout. A Taguchi technique to overcome these difficulties has emerged in practice. A Taguchi method (Olivia & Nikraz,

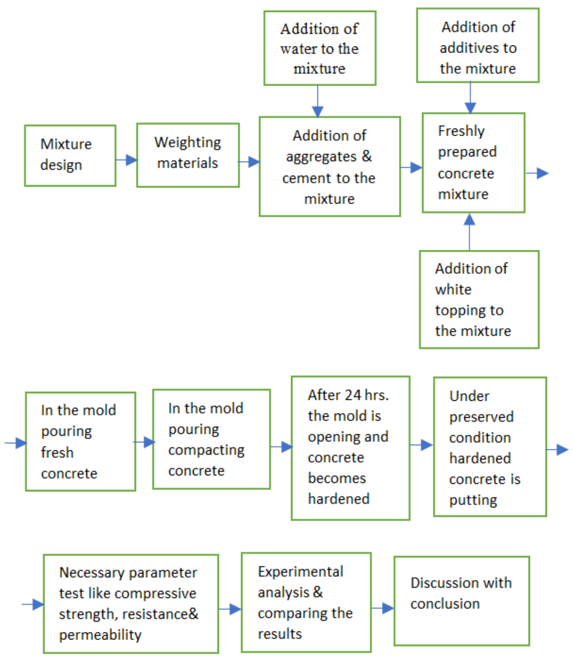


**Figure 1:** Implementing method for durability function

2012) which employs an orthogonal array and signal-to-noise ratio (S/N ratio) evaluation, was added to enhance the effectiveness of DoE. Taguchi approach has been implemented successfully for various engineering structures to clear up troubles of properties in some substances along with fly ash geopolymer concrete (Ayan *et al.*, 2011), steel fiber reinforced high energy concrete (Chang *et al.*, 2011), and recycled aggregate concrete combos (Roy, 1990; British Standard for Testing Hardened Concrete—Part 2, 2000).

As the elements are studied on this approach included a 12-level factor (white topping particles), a three-level factor (temperature of the preserving surrounding environment) and a 2-level factor (humidity of the preserving surrounding environment), the total degrees of freedom are fifteen, so an array of at least fifteen rows from Taguchi method become selected. However, for the reason that technique does not cover an array with fifteen rows, we have to go for present arrays. An to be had array in the Taguchi technique is $L_{18}(2^1{\times}3^7)$, which contains eighteen experiments but needs to be advanced because it does not include a 12-level element. For this purpose, via thinking about the method to create a 4-stage column after which an 8-stage column (Soleimanirad *et al.*, 2013), a 12-level factor was created in the table $L_{18}$. After selecting the proper table and allocating the columns suitable to every degree of freedom, the layouts for two-degree, three-degree and 12-degree elements are located inside Table 2(a).

### *Test for Durability*

On this stage, with reference to the selected elements and the number in their levels, a set of eighteen experiments was designed according to the selective orthogonal array of Taguchi technique. Moreover, it was decided that two samples must be prepared for every experiment for precision control and repeatability purposes. To perform the experiments, 36 cubic specimens with respect to the varieties of the reaction variables have been made and examined. The rest of the measured values for compressive power, resistance and permeability are confirmed in Table 2(b).

**Table 2(a):** The final $L_{18}$ design (including 12,3,2 level factors) and the amounts for reaction variables

| *Run* | $x_1$ | $x_2$ | $x_3$ |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 6 | 2 | 1 |
| 3 | 8 | 3 | 1 |
| 4 | 4 | 3 | 1 |
| 5 | 5 | 1 | 1 |
| 6 | 8 | 2 | 1 |
| 7 | 1 | 3 | 1 |
| 8 | 3 | 1 | 1 |
| 9 | 12 | 2 | 1 |
| 10 | 10 | 1 | 2 |
| 11 | 9 | 2 | 2 |
| 12 | 11 | 3 | 2 |
| 13 | 2 | 2 | 2 |
| 14 | 6 | 3 | 2 |
| 15 | 2 | 1 | 2 |
| 16 | 3 | 2 | 2 |
| 17 | 5 | 3 | 2 |
| 18 | 7 | 1 | 2 |

**Table 2(b):** The amounts for reaction variables

| *Compressive strength (kg /cm²) $y_1$* | | *Resistance (kΩ/cm) $y_2$* | | *Permeability (mm) $y_3$* | |
|---|---|---|---|---|---|
| 688 | 652 | | 963 | 35 | 33 |
| 842 | 808 | 718 | 702 | 23 | 23 |
| 1049 | 1031 | 811 | 803 | 29 | 29 |
| 853 | 815 | 741 | 729 | 23 | 21 |
| 739 | 703 | 692 | 684 | 22 | 18 |
| 979 | 949 | 799 | 781 | 31 | 31 |
| 888 | 866 | 1127 | 1123 | 30 | 30 |
| 772 | 766 | 1022 | 1016 | 37 | 33 |
| 1112 | 1108 | 675 | 665 | 33 | 33 |
| 694 | 678 | 502 | 498 | 44 | 40 |
| 758 | 772 | 671 | 655 | 40 | 38 |
| 974 | 944 | 618 | 610 | 31 | 29 |
| 695 | 657 | 1025 | 1015 | 31 | 29 |
| 756 | 728 | 590 | 518 | 24 | 22 |
| 511 | 529 | 898 | 878 | 35 | 21 |
| 697 | 665 | 1016 | 1014 | 39 | 35 |
| 759 | 751 | 656 | 642 | 20 | 18 |
| 523 | 491 | 555 | 549 | 44 | 40 |

*Compressive strength*

The 150 mm concrete cubes were used for the compressive strength while the specimens were at the age of 28 day. The manner followed throughout the check changed into in conformity with BS EN 12390-2-2000.

*Resistance*

While the experiment was in progress, the specimens were taken away from the water tank and turned back to the water after the experiment. The resistivity meter that produced 100 Hz AC was used to achieve this goal. Two copper plates (120× 100× 2 mm) with a thin layer of low slump cement paste were put on contrary faces of each saturated floor dry specimen, and the resistance became measured among them (NIST/SEMATECH e-Handbook of Statistical Methods, 2012).

*Permeability*

The 150 mm cubic specimens have been used for water penetration and the test commenced when the specimens had been at least 28 days vintage. Moreover, the water stress to a troweled surface of a specimen were not carried out. The specimens had been placed inside the apparatus and the water pressure of (500 ± 50) kPa for (72 ± 2) h had been used in line with BS EN12390-8:2009 (Muthukumar *et al.*, 2003).

### *Optimization Method*

In optimization of a multiple response variable, the final optimized solution typically cannot be the most appropriate for one of the response variables. There are specific techniques to get to the optimal reaction. In this paper the desirability function (Eltawahni *et al.*, 2013) has been applied in order to optimize more than one reaction variable of durability. The approach identifies operating situations 'x' that offers the most acceptable response values. For every response $y_i(x)$, a desirability feature assigns $d_i(y_i)$ numbers among 0 and 1 to the all-likelihood values of $y_i$, with $d_i(y_i) = 0$ which represents a totally undesirable cost of $y_i$ and $d_i(y_i) = 1$ representing a perfectly desirable or best response price. The individual desirability is then merged the usage of the geometric suggest, which gives the general desirability D and may be evaluated through Eq. (2): (Montgomery, 2012)

$$D = (d_1(y_1)d_2(y_2) \dots \dots d_n(y_n))^{1/n} \qquad (2)$$

Where *n* denotes the number of responses. When any response of $y_i$ is completely undesirable ($d_i(y_i)=0$) then it must be noted that the overall desirability is considered zero. So, the individual desirability function is expressed as,

$$d_i(\hat{y}_i) = \begin{cases} 0 & if \;\; \hat{y}_i(x) < \hat{P}_i \\ \left(\frac{\hat{y}_i(x)-P_i}{Q_i - P_i}\right)^e & if \;\; P_i \le \hat{y}_i(x) \le Q_i \\ 1 & if \;\; \hat{y}_i(x) > R_i \end{cases} \qquad (3)$$

Let $P_i$, $Q_i$ denotes lower and upper unit, respectively and the $R_i$ denotes the target value for the variable $Y_i$ and $P_i \le Q_i \le R_i$ and the exponent 'e' determines how important it is to hit the target (Eltawahni *et al.*, 2013).

## Results and Discussion

### *Effects of S/N Ratio on the Compressive Strength*

The main objective of the durability test is to improve the compressive strength. also it helps to identify the stability of transaction response time over the test of duration. For the given factors, the S/N Ratio of each level had to be calculated and used in order to evaluate delta values. These delta values help determine the specimen's rank (Montgomery *et al.*, 2012; Minitab15 software). The outcomes are shown in Tables 3 and 4.

### *Effects of S/N Ratio on the Resistance*

The main objective of the durability test is to improve the resistance. For the given factors, the S/N ratio of each level had to be calculated and used in order to evaluate delta values. These delta values help determine the specimen's rank (Montgomery *et al.*, 2012; Minitab15 software). The outcomes are shown in Tables 5 and 6.

### *Effects of S/N Ratio on the Permeability*

The main objective of the durability test is to reduce the permeability. For the given factors, the S/N Ratio of each level had to be calculated and used in order to evaluate delta values. These delta values help determine the specimen's rank (Montgomery *et al.*, 2012; Minitab15 software). The outcomes are shown in Tables 7 and 8.

We observe the highest value of delta variables from (Tables 3–8). So, the maximum effect of PCC particle depends

**Table 3:** Outcomes of S/N ratio for compressive strength

| *Level* | *S/N ratio for PCC particles* | *S/N ratio for temp. of the preserved surrounding atmosphere* | *S/N ratio for humidity of the preserved surrounding atmosphere* |
|---|---|---|---|
| 1 | 54.98 | 56.92 | 59.18 |
| 2 | 57.82 | 57.86 | 57.36 |
| 3 | 60.94 | 59.36 | |
| 4 | 59.68 | | |
| Delta | 5.98 | 2.44 | 1.82 |
| Rank | 1 | 2 | 3 |

**Table 4:** Based on S/N ratio, optimized level for compressive strength

| *Rank* | *Factor* | *Optimized level* | *S/N Ratio* |
|---|---|---|---|
| 1 | PCC particles | 3 | 60.94 |
| 2 | Temperature | 3 | 59.36 |
| 3 | Humidity | 1 | 59.18 |

**Table 5:** Outcome of S/N ratio for resistance

| *Level* | *S/N ratio for PCC Particle* | *S/N ratio for temp. of the preserved surrounding atmosphere* | *S/N ratio for humidity of the preserved surrounding atmosphere* |
|---|---|---|---|
| 1 | 59.63 | 58.64 | 59.63 |
| 2 | 60.76 | 57.32 | 57.19 |
| 3 | 58.23 | 57.98 | |
| 4 | 54.96 | | |
| Delta | 5.8 | 1.32 | 2.44 |
| Rank | 1 | 3 | 2 |

**Table 6:** Based on S/N ratio optimized level for resistance

| *Rank* | *Factor* | *Optimized level* | *S/N ratio* |
|---|---|---|---|
| 1 | PCC particles | 2 | 60.76 |
| 2 | Temperature | 1 | 59.63 |
| 3 | Humidity | 1 | 58.64 |

**Table 7:** Outcomes of S/N ratio for permeability

| *Level* | *S/N ratio for PCC Particle* | *S/N ratio for temp. of the preserved surrounding atmosphere* | *S/N ratio for the humidity of the preserved surrounding atmosphere* |
|---|---|---|---|
| 1 | -34.68 | -31.06 | -29.43 |
| 2 | -29.32 | -29.16 | -30.46 |
| 3 | -32.19 | -28.86 | |
| 4 | -28.16 | | |
| Delta | 6.52 | 2.20 | 1.03 |
| Rank | 1 | 2 | 3 |

**Table 8:** Based on S/N ratio optimized level for permeability

| *Rank* | *Factor* | *Optimized level* | *S/N ratio* |
|---|---|---|---|
| 1 | PCC particles | 4 | -26.81 |
| 2 | Temperature | 3 | -28.25 |
| 3 | Humidity | 1 | -28.95 |

upon the response variable as per the Taguchi technique and selecting suitable levels with highest degree of S/N are considered optimum. The graphical representation of S/N ratio for compressive strength, resistance and permeability of PCC particle is shown in Figure 2, the S/N ratio for the temperature of preserved surrounding atmosphere for compressive strength, strength and permeability is represented in Figure 3. The variation in the humidity of the preserved surrounding atmosphere for compressing strength, resistance and permeability is reflected in shown in Figure 4.

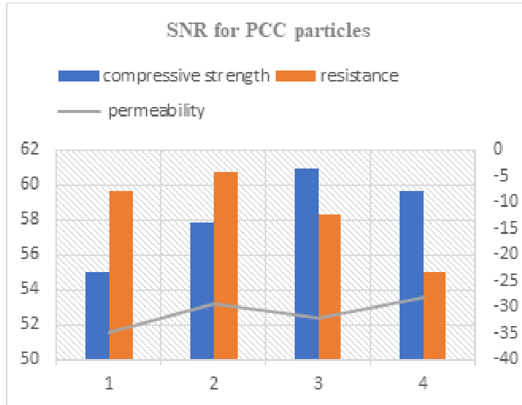


**Figure 2:** SNR for PCC particle

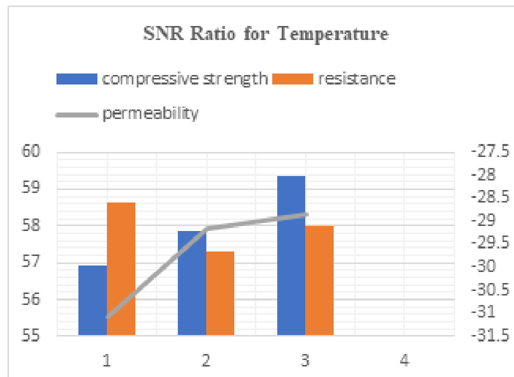


**Figure 3:** SNR for temperature

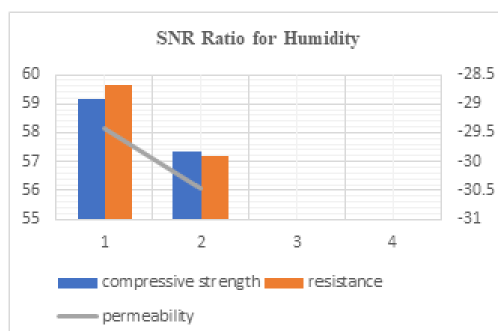


**Figure 4:** SNR for humidity

## Conclusion

The effect of considered particles using different level on the variables of compressive strength, resistance and permeability with durability has been analyzed. For design of the experiment, depending on the methods, especially the Taguchi technique, the optimum level of each response was separately verified. Further, each variable was formulated and in the following step the durability function was applied for multi-variable optimization and evaluation of final levels. Finally, the optimized values indicate that the concrete made in combination with a standard temperature particle and in a preserved scenario will have the highest durability.

Compressive strength, resistance and permeability in terms of SNR help to understand the rank of the specimen with the proper knowledge of levels.

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