Case Studies in Construction Materials 21 (2024) e03572

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Investigation of The Use of Nano Powder On Roller Compressible Fibrous Concrete Roads

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ARTICLE INFO

Keywords:
Concrete road
Roller compacted concrete pavements
Taguchi method

ABSTRACT

Despite the fact that our country's road network is inferior to that of industrialized countries, the volume of motor traffic is increasing. Thus, optimal solutions are imperative during both project and construction phases of highway investments. Concrete superstructures offer an alternative to flexible superstructures in various regions globally, including airport runways, warehouses, urban roads, streets, highways and industrial buildings. The objective of this study was to enhance the compressive and flexural strength of concrete and provide resistance against abrasion. To achieve this, a roller compressible concrete (RCC) mixture design was developed by incorporating basalt fiber, nano TiO_2, and nano Fe_2O_3 additives. The experimental results were subjected to statistical analysis via the technique of analysis of variance (ANOVA). The findings of the study indicated that the strength performance of the optimal RCC mixture design reinforced with nano powder and fibers was superior to that of conventional concrete. Upon examination on a material basis, it was determined that the compressive strength exhibited an increase when the water/binder ratio was utilised within the range of 0.38–0.4. As the utilisation of nano-Fe_2O_3 and basalt fiber materials increased, their compressive strength exhibited a corresponding enhancement. The incorporation of basalt fiber into the composite material resulted in an increase in flexural strength at all ratios where it was utilised. It can be concluded that basalt fiber has the greatest potential for enhancing flexural strength. The optimal water-to-binder ratio for flexural properties is between 0.34 and 0.38. While nano powders can have a positive impact, they cannot achieve the maximum level of strength. For improving abrasion resistance, it was established that reducing the water/cement ratio, using fly ash, basalt fiber, and nano Fe_2O_3 in the mixture decreased abrasion. However, the usage of nano TiO_2 did not have a significant positive effect. The material with the least effect on compressive, flexural and abrasion resistance was identified as nano TiO_2. When materials other than nano TiO_2 are utilised in accordance with the established optimal mixture calculation, the durability of the resulting RCC road will reach the requisite standard.

1. Introduction

Concrete pavements are often used as an alternative to flexible pavements worldwide. When designed and constructed appropriately, they can withstand high volumes of traffic. However, the initial construction costs are high and may not seem economical at

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https://doi.org/10.1016/j.cscm.2024.e03572
Received 31 January 2024; Received in revised form 2 July 2024; Accepted 26 July 2024
Available online 27 July 2024
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first glance. When comparing the economics of rigid and flexible pavements, despite their higher initial construction costs, rigid pavements are more cost-effective over a period of 20 years or more due to lower maintenance costs. Concrete roads are the most cost-effective solution, particularly for roads with weak subsoil and high traffic volume. This study presents a concrete pavement design aimed at reducing pavement construction, maintenance, and repair costs while increasing durability and longevity compared to flexible pavement. To enhance the physical and mechanical properties, an analysis was conducted to determine the optimal mixture ratio for the zero-slump RCC road, contrasting with traditional concrete roads. When a load from a wheel pass over a concrete slab, it generates compressive, tensile, and flexural stresses. After the wheel passes, the stresses change direction and disappear. On a concrete road with high volumes of heavy vehicle traffic, continuous and frequent stress changes occur. The continuous stresses that occur in the plate, which vary between tension and pressure, result in a reduction in the load-carrying capacity of the material over time. Concrete roads can become slippery over time due to abrasion. The study aims to minimize the effects of flexural, pressure, and abrasion.

Concrete is a composite material composed of cement, water, and aggregate. In recent years, numerous studies have been conducted on composite materials based on cement. In reviewing the studies, it was noted that attempts have been made to increase the strength of concrete by incorporating a variety of materials. Various methods have been used to increase the strength of the material, including the use of different types of aggregates [1–3], alternative grouts instead of cement [4,5] and different additives [6]. Although waste aggregates are mainly used as aggregate replacements, there is a wide range of pozzolanic materials that can be used to replace cement. When examining studies on RCC roads, which are the subject of this research, it is evident that various materials have been tested in concrete. The range of materials used in paving concrete is as diverse as that used in traditional concrete. In the studies examined, the mechanical and physical effects were investigated by using different materials on concrete roads, and the usability of roller-compacted concrete in road construction was examined [7,8]. RCC is a low-cost, easy-to-produce mix that contains a higher proportion of aggregate than conventional concrete and has zero slump when fresh [9]. Additionally, due to its zero slump, the road can be opened to traffic more quickly. RCC technology is commonly used in dam construction. However, its use in road construction is increasing. When a large amount of fly ash is used in RCC production along with cement, it is possible to obtain alternative materials to portland cement that have high compressive and tensile strength. These materials are suitable for use in structural applications, road pavements, and large industrial grounds [10]. The strength values of the roller-compacted concrete mixture increase at all ages compared to the control sample as the amount of fly ash increases.

Additionally, the concrete void volume decreases and the durability properties improve [11,12]. The desired characteristic of additive materials added to cement-based materials is a low void ratio. Additives cannot provide sufficient impermeability due to their micro size. Therefore, the use of nanomaterials is necessary. The use of pozzolana materials in road concrete design is prevalent in literature studies. Improving the properties of cement-based composite materials with various nanomaterial additives can increase impermeability. In this study, the aim was to produce composite materials with greater strength and performance and a lower void ratio by using nano Fe_2O_3 and nano TiO_2 as nanomaterials.

Various methods have been proposed to increase the durability and longevity of concrete roads, including the use of different materials in roller-compacted concrete. Various types of fibrous materials have been investigated to enhance the flexural strength of the road concrete. The mechanical and physical properties of concrete have long been known to benefit from the inclusion of fibers in cement-based composites. Several studies have shown that the inclusion of fibers in concrete increases its flexural strength [13,14]. The only difference lies in the effect rates of fiber types on strength [15]. While the use of fiber in concrete pavements is limited, there are various design methods available, each with its own unique approach. In this study, basalt fiber was chosen as the reinforcement to enhance the tensile and abrasion resistance of the concrete. The literature indicates that basalt fiber is incorporated at a ratio of 1–10 kg per cubic metre of concrete, contingent on the desired quality of concrete.[16] In her study, Çevik employed basalt fiber at rates of 2 kg/m^3, 3 kg/m^3, and 4 kg/m^3[17]. In a separate study, basalt fiber was incorporated into the cement at a dosage of 0.25 %, 0.5 %, 0.75 % and 1 %. The corresponding kg/m^3 amounts for these ratios are 6.75 kg/m^3, 13.5 kg/m^3, 20.25 kg/m^3, 27 kg/m^3, respectively. [18] In their mixtures, Lopresto and her associates utilised basalt fiber with a density of 2.8 kg per cubic metre [19]. Bilim conducted research on the effects of adding basalt fiber by volume to concrete, with the addition of 1 %, 2 % and 3 % respectively [20]. Considering all the specified studies, the amount of basalt fiber has been chosen to be within the range of 1–10 kg/m^3 of the total concrete volume, in accordance with values close to those found in the literature. Recently, nano materials have also gained popularity and are being considered as a primary option [21]. Although research on fiber concrete roads and nano material concrete roads have been conducted separately, there is also an idea to combine them into a hybrid. Studies have been conducted to design high-strength concrete roads by using a combination of various fibers and nanomaterials [22].

In this study, concrete road design was achieved by using fiber and nano materials together. Unlike other studies, the concrete road was designed for roller compaction and was made using a combination of basalt fiber, nano Fe_2O_3, nano TiO_2 and fly ash. The concrete road has been designed with roller-compressible concrete and reinforced with fiber and nano materials to increase its durability. Thus, this overview will cover many of the other conducted studies. The experimental design was created using the Taguchi method, and the mechanical and physical properties of the samples were determined through experimentation. The Taguchi method is a statistical optimization technique developed by Genichi Taguchi in 1950. It aims to determine the optimal combination of values for factors that have a significant impact on the result, even in cases of uncertainty [23]. The Taguchi method comprises four stages: design, preparation, analysis, and verification. One advantage of this method is that it can provide a full factorial design with a limited amount of experimental data. Furthermore, to minimize the difference in the result, the signal-to-noise ratio (S/N) is maximized by increasing the ratio of controllable factors to uncontrollable factors [24,25].

The compounds prepared by the Taguchi method were subjected to compression, flexural and abrasion tests, with the results. Optimum mixture ratios were determined for each experiment, and validation samples were prepared based on these ratios, according to the results[26]. Additionally, the results of the first experiments were examined, analysis of variance (ANOVA) was performed, the

statistical parameters of different models for estimating optimum values were studied, and the contribution of each parameter to the mechanical-physical properties of concrete was evaluated. The study examined whether the results of the verification experiment fell within the confidence interval.

2. Experimental Material

2.1. Cement

In this research, TS EN 197–1 [27] compliant Askale Cement produced CEM I-42.5 R cement was utilized. The properties of the cement used are given in Tables 1–3.

2.2. Mixing Water

In preparing cement mortars, drinking water sourced from the city network following the regulations set out in TS EN 1008 [28] was utilized.

2.3. Aggregate

The study examined aggregates of three different sizes: 0–5, 5–12, and 12–22 that adhere to the TS 3530 EN 933–1 standard [29]. Aggregates are a product of Mazlumoglu Building Construction Contracting Construction Materials Insulation Electricity Contracting Cleaning Services Industry and Trade Ltd Company. It has been determined through experimentation that the gradation of the aggregate falls within the lower and upper limit values.(Figs. 1–7)

2.4. Additives

2.4.1. Basalt Fiber

Basalt fiber was acquired from Dost Chemistry Industry Raw Materials industry trade limited company. The properties of the basalt fiber used are given in Table 4.

2.4.2. NanoFe_2O_3

The characteristics of the Fe_2O_3 nanopowder, acquired from Nanografi Nano Technology AŞ. The properties of the nano Fe_2O_3 used are given in Table 5.

2.4.3. Nano TiO_2

The characteristics of the TiO_2 nano powder, acquired from Nanografi Nano Technology. The properties of the nano TiO_2 used are given in Table 6.

2.4.4. Fly Ash

The fly ash used in this study was produced in accordance with TS EN 450–1 [30] and obtained from Yatagan Thermal Energy Production Corporation. The properties of the fly ash used are given in Tables 7,8.

2.4.5. Plasticizer

The plasticizer was supplied from Master Builders Solutions Construction Chemicals Industry and Trade Limited Company. The characteristics of the plasticizing agent for concrete, Master Pozzolith-515, manufactured in compliance with TS EN 934–2+A1 [31]. The properties of the pasticizer used are given in Table 9.

3. Experimental Method

3.1. Taguchi Method

The Taguchi method was developed by Genichi Taguchi in 1950 and it is a powerful tool for the design of high-quality systems. Many methods and ideas for developing products and processes were created by Dr Genichi Taguchi. Some approaches that can be employed in the design of a product or process are the Taguchi Loss Function, System, Parameter and Tolerance Design. Furthermore,

Table 1
Chemical Properties of Cement.

CHEMICAL PROPERTIES									
SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**Na_2O**	**K_2O**	**Cl-**	**Serbest CaO**
18.21	4.54	3.1	63.5	2.57	2.82	0.22	0.65	0.0144	0.49

Table 2
Physical Properties of Cement.

PHYSICAL PROPERTIES						
Fineness (45 nm over sieve%)	**Density (g/cm^3)**	**Surface area (cm^2/g)**	**Hardening Start (minutes)**	**End of hardening (minutes)**	**Displacement (mm)**	**Requirement (%)**
7.17	3.12	3616	146	189	1	29.5

Table 3
Mechanical Properties of Cement.

MECHANICAL PROPERTIES		
Flexural Strenght	**2 Days**	**28 Days**
N/mm^2	27.72	58.81



Fig. 1. Aggregates.



Fig. 2. Basalt Fiber.

an alternative experimental methodology known as "Orthogonal Arrays" is utilized to decrease the number of experiments under potential reliability conditions [32]. The performance of a product or process can be impacted by the environmental conditions during its use and the components used during production, as asserted by Taguchi. The ideal values for the factors of the product or process must be ascertained while considering the environmental conditions that the product or process will be utilized and the conditions of the components utilized in production. The Taguchi experimental approach applies high fraction experiments that employ orthogonal



Fig. 3. Nano Fe_2O_3.

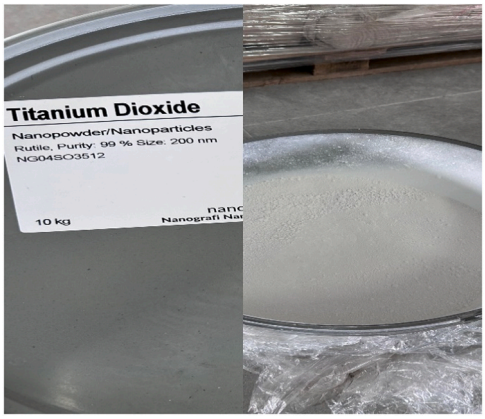

Fig. 4. Nano TiO_2.

arrays in identifying optimal values for controllable factors. Verification experiments are conducted under conditions of optimality obtained through the analysis of data acquired at the end of the experiments, to determine achievability of the expected outcome [33]. If the characteristics measured in orthogonal arrays are continuous, multiple observations from each experiment of the design parameters matrix are used to calculate a measure known as the performance statistic. Performance statistics values are calculated to improve estimates of design parameters. Taguchi also suggested that the S/N ratio should be used as a performance statistic. The signal represents the desirable effect of the product, while noise denotes the interfering factors that negatively affect the signal [34]. The S/N ratio considers the average and spread of test outcomes. Taguchi divided the problems in practice into three according to the type of target specified in the quality loss function and defined a different S/N for each, shown in Table 10 [35].(Tables 11,12)

3.2. Experimental Design

The experimental design comprises of four levels and five parameters. According to the Taguchi method, it has been considered appropriate to use the L16 orthogonal index, resulting in the emergence of 16 distinct mixing ratios. The experimental studies were carried out in two steps. In the first step, the mixes were prepared according to the L16 orthogonal index and the necessary tests were carried out to determine the optimum mix calculations. In the second step, verification samples with the optimum values were prepared and subjected to the necessary tests. The results obtained were analyzed using ANOVA.

The cement dosage in the mix was set at 350 kg/m^3 according to the Technical Specification for Concrete Pavements of the General Directorate of Highways [36]. Accordingly, binders were used as a percentage of the cement dosage. The amount of basalt fiber was determined by the weight of the total mixture. Appropriate proportions of the materials used were selected by compiling studies from the literature. The quantities of materials used in 1 m^3 of mixture are given in the Table 13 according to the levels determined.

The water/binder ratio employed in the mixture was determined in accordance with the RCC ratios, rather than the traditional concrete ratios. In the RCC mixture calculation, an attempt was made to achieve a zero-slump concrete by maintaining the water/binder ratio below that of conventional concrete.

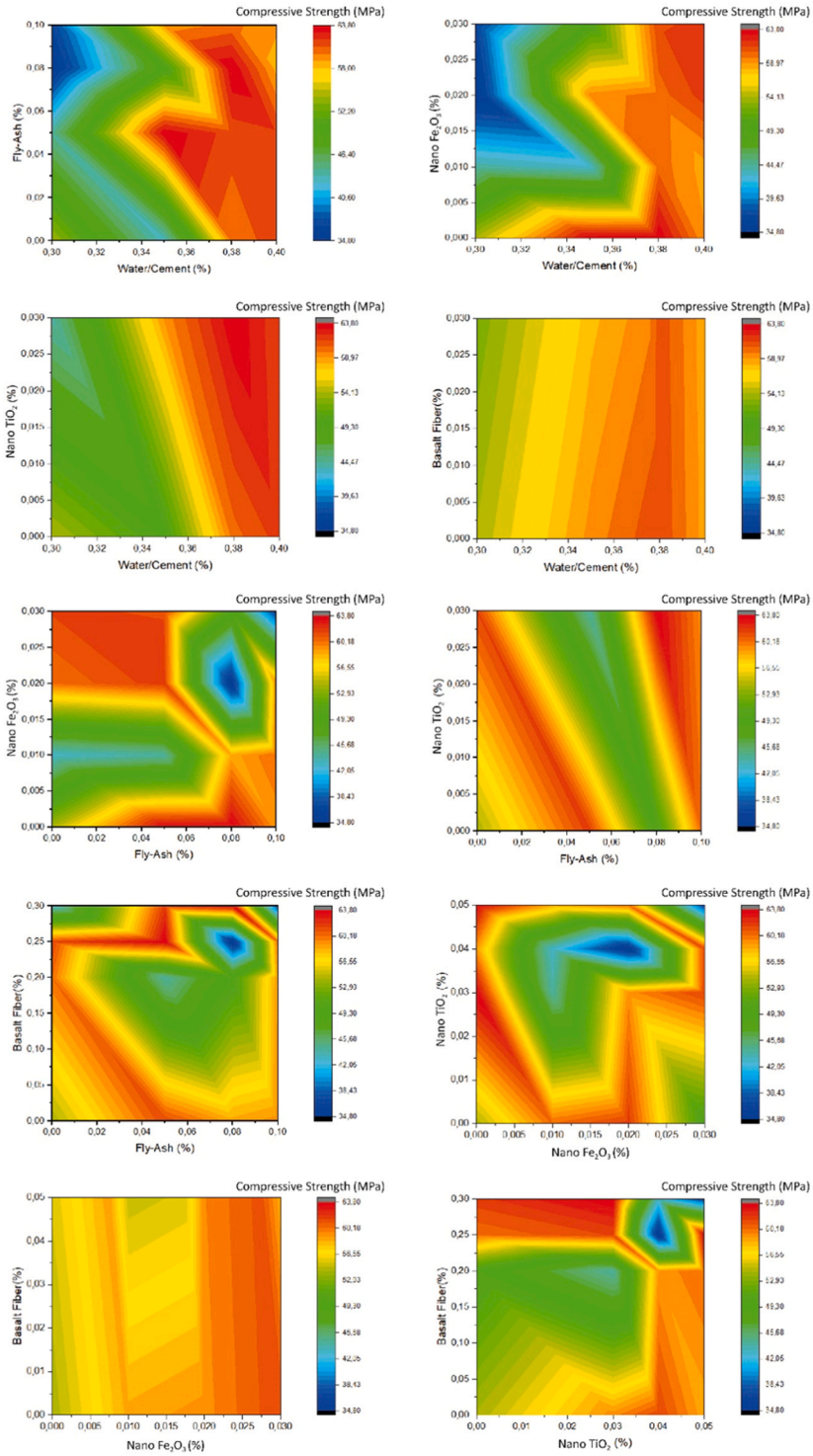

Fig. 5. Compressive Strength Color Graphs.

4. Results

For the initial step of the study, three samples were prepared from each mixture to undergo compressive strength, 3-point flexing, and abrasion tests. Therefore, a total of 144 samples were prepared. The samples were placed in the curing pool for 28 days, and on the 28th day, pressure, flexural and abrasion tests were conducted. Compressive strength testing was performed on 48 cube samples

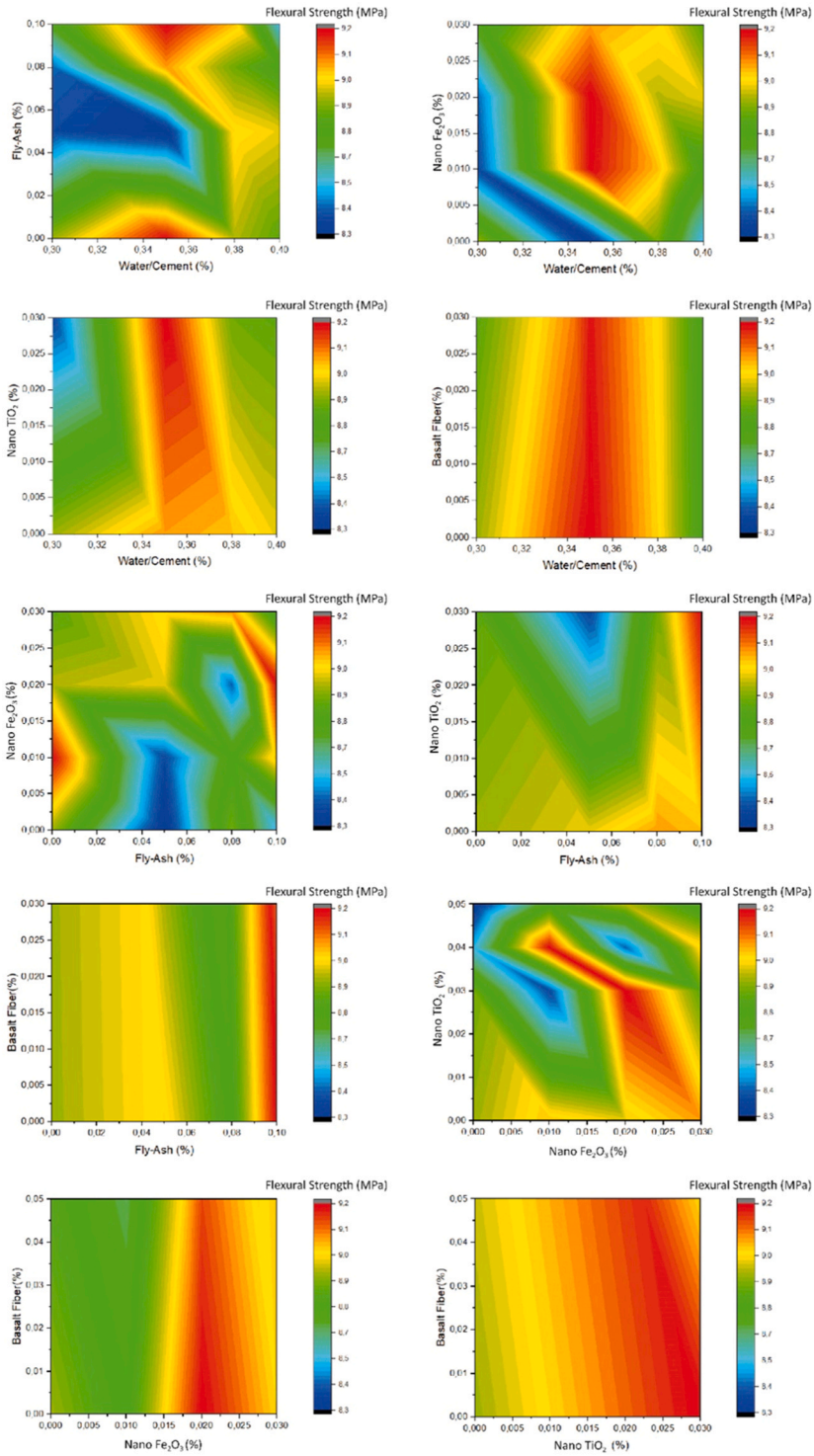

Fig. 6. Flexural Strength Color Graphs.

(150x150x150 mm) that were kept in a curing pool. 48 beam samples (40x100x100 mm) were subjected to three-point flexural testing, while the remaining 48 cube samples (70x70x70 mm) were subjected to Bohme abrasion testing. The results of the experiments are presented below.

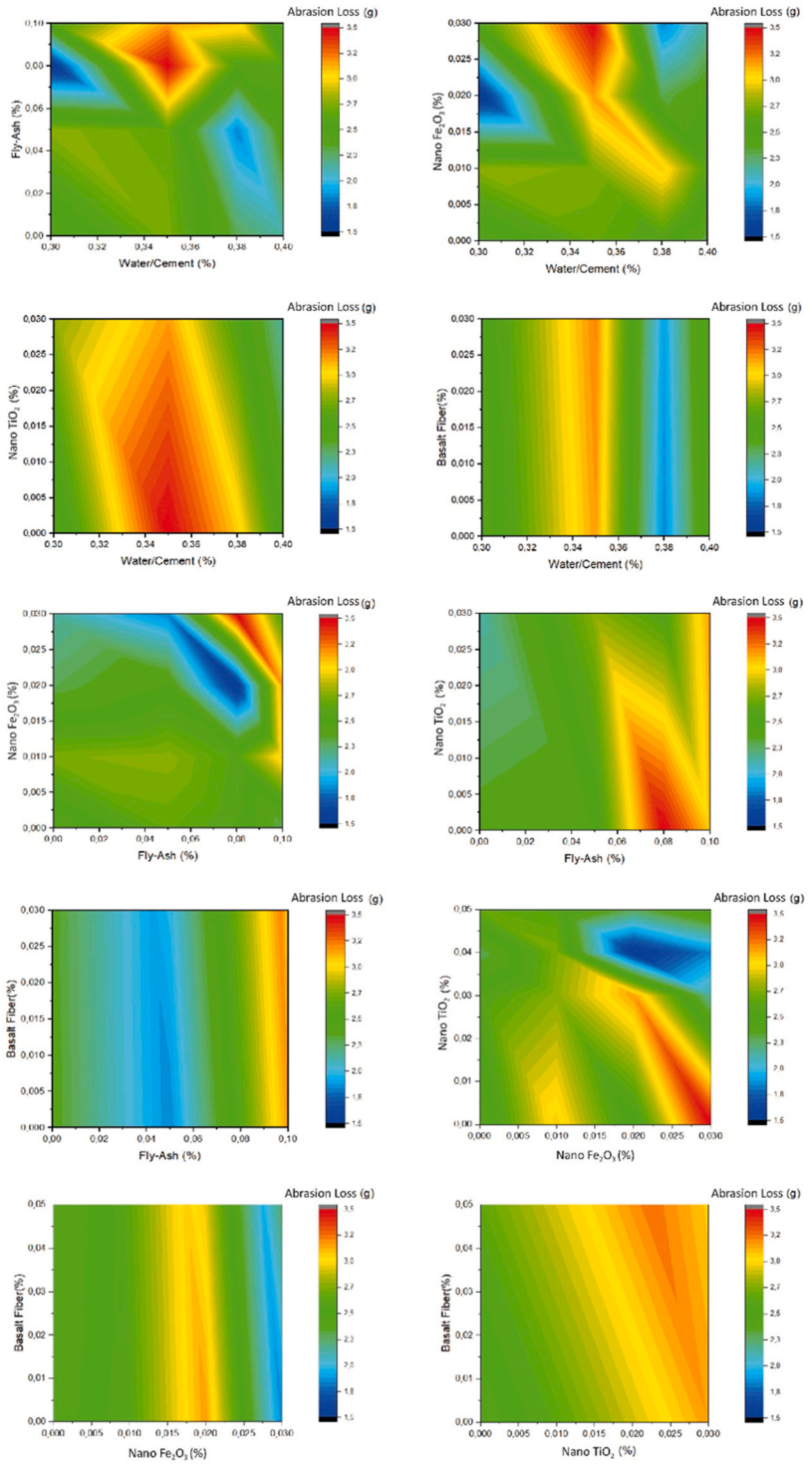

Fig. 7. Abrasion Losses Color Graphs.

4.1. Compressive Strength Test Results

Compressive strength testing was carried out in accordance with TS EN 12390–3 [37] using a Besmak brand testing machine. Three samples were tested per group, and subsequently, the average compressive strength of these samples was calculated. The compressive strength was found to be highest in the 11th group and lowest in the 7th group. The study investigated the changes in compressive

Table 4
Basalt Fiber Properties.

CHARACTERISTIC	VALUES
Tensile Strength	4840 MPa
Modulus Of Elasticity	89 Gpa
Application Temperature Limits	- +982°C
Specific Gravity	2.60–2.80 gr/cc
Fiber Diameter	9–23 mikron
Fiber Length	24 mm

Table 5
Nano Fe_2O_3 Properties.

TECHNICAL CHARACTERISTICS	VALUES
Gamma, Purity	%99.55, Dimension: 18–38 nm
Purity	%99.55
Colour	Red Brown
Average particle size (nm)	18–38
Morphology	Spherical
Surface Area (m^2/g)	>55
Element analysis (%)	Ca:0.003, Cr:0.01, Mn: 0.14, Al:0.05, SiO_2: 0.091

Table 6
Nano TiO_2 Properties.

TECHNICAL CHARACTERISTICS	VALUES
Rutile	%99.5+, Dimension: 200 nm
Particle Size	200 nm
Purity of rutile	99.5+ %
Colour	White
Specific Gravity: 4.1 g/cm^3	4.1 g/cm^3
Bulk Density	1.1 g/cm^3
Loss at 105°C	0.6 %
Oil Absorption	18/100 cm^3/g
Water Requirement	25/100 cm^3/g
Surface area	19 cm^3/g

Table 7
Chemical Properties of Fly Ash.

Chemical Properties		
Element	**Unit**	**Results**
SiO_2	%	54.47
Al_2O_3	%	24.17
Fe_2O_3	%	6.415
CaO	%	5.342
MgO	%	2.509
SO_3	%	0.717
Na_2O	%	1.358
K_2O	%	3.309
Cl-	%	0.099
Total Phosphate	%	0.145
Soluble Phosphate	mg/lt	3.2752
Free CaO	%	0.07
Reactive SiO_2	%	39.77
Reactive CaO	%	-
Total Alkaline	%	3.54
Glow Loss	%	1.32

strength resulting from the dual use of materials in the concrete mixture, based on experimental results. Based on the color graphs, it can be observed that the water/binder ratio range that maximizes compressive strength is between 0.38 and 0.4. The incorporation of fly ash into the concrete led to varying improvements in strength, dependent upon the nature of the secondary material utilized. When evaluating the fly ash-nano Fe_2O_3 and fly ash-nano TiO_2 pairs individually, an inverse relationship can be observed between them. In other words, high compressive strength is achieved when the quantity of nano Fe_2O_3/nano TiO_2 is low, and the amount of fly ash is

Table 8
Fly Ash Physical Properties.

Physical Specifications	Unit	Results
45 nm on the sieve	%	29.54
Specific Surface	cm^2/g	2520
Specific Gravity	g/cm^3	1.97
Displacement (mm)	mm	1
Hardening Start	min	160
End of hardening	min	220
Water Requirement	%	103.1
Activity Index 28 Days	%	77.1

Table 9
Plasticizing Additive Technical Specifications.

Technical Properties	
Structure of the material	Modified Lignin Sulfonate Based
View	Dark Brown- Liquid
Specific Gravity (at 20 °C)	1.146–1.206 kg/lt
pH Value	5–7
Alkaline Content (%)	≤10
Chlorine ion content (%)	≤0,10

Table 10
S/N Ratios Characteristic Types.

Characteristic Type	S/N
Higher-Better	$-10\log\left(\frac{1}{n}\sum_{i=1}^{r}\frac{1}{y_i^2}\right)$
Nominal- Best	$-10\log\left(\frac{y^{-2}}{s^2}\right)$ or $10\log\left(\frac{s^2}{y^{-2}}\right)$
Lower - Better	$-10\log\left(\frac{1}{n}\sum_{i=1}^{r}y_i^2\right)$

y_i = Performance characteristic i. observation value
n = Number of tests in an equation
S^2 = Variance of observation values

Table 11
Parameters and Levels.

Parameters	Levels			
	1	**2**	**3**	**4**
Water/Binder Ratio	0.3	0.35	0.38	0.4
Fly Ash (%)	0	5	8	10
Nano Fe_2O_3 (%)	0	1	2	3
Nano TiO_2 (%)	0	3	4	5
Basalt Fiber (kg/m^3)	0	2	2.5	3

high, and vice versa. This indicates that fly ash and nano powders ought not to be used in equivalent measures. Considering the correlation between fly ash and basalt, the region where their combined usage has a positive impact on compressive strength is rather limited. It can be inferred that the combined application of two materials has negligible impact on the compressive strength. Considering the combined utilization of nano powders, it can be asserted that the compressive strength experiences a moderate increase. When comparing the use of basalt fiber with nano powders, it is apparent that the addition of nano-Fe_2O_3 significantly enhances concrete strength, while the addition of nano TiO_2 only moderately increases compressive strength. The most effective factors for increasing compressive strength are water to cement ratio, nano Fe_2O_3, and basalt fiber. It can be concluded that the combination of basalt fiber and nano Fe_2O_3 provides the optimal outcome.

4.2. Flexural Test Results

The samples underwent a three-point flexural test using a Besmak brand sample flexural test device, following the TS EN 12390–5

Table 12
Experimental Plan.

Group Number	Water/Binder Ratio	Fly Ash (%)	Nano Fe_2 O_3 (%)	Nano Tio_2 (%)	Basalt Fiber (kg/m^3)
1	0.3	0	0	0	0
2	0.3	5	1	3	2
3	0.3	8	2	4	2.5
4	0.3	10	3	5	3
5	0.35	0	1	4	3
6	0.35	5	0	5	2.5
7	0.35	8	3	0	2
8	0.35	10	2	3	0
9	0.38	0	2	5	2
10	0.38	5	3	4	0
11	0.38	8	0	3	3
12	0.38	10	1	0	2.5
13	0.4	0	3	3	2.5
14	0.4	5	2	0	3
15	0.4	8	1	5	0
16	0.4	10	0	4	2

Table 13
Dosages Of Materials Used In The Experiment.

Levels	Water (lt)	Cement (kg)	Aggregate (kg)	Fly Ash (kg)	Nano Fe_2O_3 (kg)	Nano TiO_2 (kg)	Basalt Fiber (kg)
1	105	350.0	545	0.0	0.0	0.0	0
2	123	318.5	526	17.5	3.5	10.5	2
3	133	301.0	515	28.0	7.0	14.0	2.5
4	140	287.0	507	35.0	10.5	17.5	3

[38] standard. The investigation examined changes in flexural strength resulting from the combined use of materials in the concrete mixture, based on the obtained experimental data. When a water/binder-fly ash combination is used, significant declines in flexural strength are observed as the fly ash ratio increases. Thus, it can be concluded that a high fly ash ratio should be avoided when using water/binder and fly ash in combination. The flexural strength of the water/binder and nano Fe_2O_3 mixture exhibits an increase as the water/binder ratio surpasses 0.36. When employing a combination of nano TiO_2 and a water/binder pair, it is observed that the flexural strength is at its minimum when the concentration of nano TiO_2 is high and the ratio of water to cement is low. It can be said that optimum values occur when the water/cement ratio is used in the range of 0.34–0.38. The beneficial impact of basalt fiber on flexural can be observed in nearly all ratios and materials it is combined with. Furthermore, an analysis of the correlation between fly ash and basalt fiber reveals that the flexural strength reaches its peak when the fly ash ratio is at its highest level. Based on the usage rates of fly ash and nano powders, it appears that there are very few points at which the flexural strength reaches its maximum size. It can be deduced that basalt fiber is the most impactful material for enhancing flexural strength and that the proportionate use of fly ash can increase it. Furthermore, it can be inferred that the flexural strength generally experiences a positive influence from the water/cement ratio. However, while nano powders are capable of positively affecting the flexural strength, they fail to achieve the maximum size.

4.3. Bohme Surface Abrasion Test

The samples underwent bohme surface abrasion test using a Baz Machine brand sample abrasion test device, following the TS 2824 EN 1338 [39] standard. The weights and mass-volume losses of the samples were calculated before and after the experiment. The study examined the alterations in weight reduction resulting from the concurrent use of materials in the concrete mixture, based on the obtained experimental findings. The aim of the studies is the reduction of abrasion and deterioration of concrete roads under wheel loads. Upon examination of the graphs, it is evident that the water/cement ratio diminishes the quantity of abrasion at almost all ratios. When nano TiO_2 is used alone, the amount of abrasion is higher than in other water/cement ratio pairs. Fly ash has been observed to reduce abrasion loss in almost all materials in which it is used. Examining the overall graphs, it can be inferred that the inclusion of nano TiO_2 does not have a favourable impact on the level of abrasion. Unlike nano TiO_2, it is observed that nano Fe_2O_3 and basalt fiber have a significant impact in reducing abrasion loss within the materials utilized. It can be concluded that the reduction of abrasion is achieved by the water/cement ratio, fly ash, basalt fiber and amount of nano Fe_2O_3 used in all materials. However, nano TiO_2 does not appear to have a significantly positive effect.

5. Taguchi Statistical Analysis Methods and Anova

5.1. Analysis of Compressive Strength Test Results

The compressive strength values were used to calculate the S/N ratios for each experiment. Table 14 displays the average S/N ratios for each parameter level.(Table 15)

It is seen that the highest S/N average value is at the water/binder ratio at the 3rd level. Accordingly, it can generally be said that the water/binder ratio is the most effective factor in compressive strength. As a high compressive strength can be advantageous for concrete roads, the S/N ratios in Table 14 were evaluated based on the higher-better characteristic. The resulting optimum mix ratios are shown in Fig. 8. The optimum mix ratios for compressive strength are therefore: water/binder ratio level 3, fly ash level 2, nano Fe_2O_3 level 1, nano TiO_2 level 2 and basalt fiber level 1.(Fig. 9)

A variance analysis was conducted to ascertain the impact of the compressive strength test results obtained from the samples on the parameters. Subsequently, the effect ratios were calculated.

In addition, the compressive strength was estimated through ANOVA and compared to the determined optimum values at a 95 % confidence interval. According to the regression analysis, the mathematical model for compressive strength is;

Compressive Strength (MPa) = - 42.73 + 2.976 (Estimated Compressive Strength (MPa)) - 0.02091 (Estimated Compressive Strength (MPa))^2

5.2. Analysis of Flexural Test Results

The signal-to-noise ratios were calculated for each trial based on the obtained flexural strength values. The S/N ratios for each level of the parameters were calculated and presented in Table 16.(Table 17)

At level 1, nano TiO_2 has the highest S/N average. Therefore, it is generally concluded that the ratio of nano TiO_2 is the most influential factor on flexural strength. As a high flexural strength value offers an advantage on concrete roads, the mix designs in Table 16 have been evaluated according to the higher-better principle and the resulting optimum mix designs are shown in Fig. 10. The ideal ratios for maximum flexural strength are as follows: the water/binder ratio should be at the 3rd level, fly ash at the 1st level, nano Fe_2O_3 at the 4th level, nano TiO_2 at the 1st level, and basalt fiber at the 1st level.(Figs. 11–13)

Variance analysis was conducted to ascertain how the results of the flexural strength test affected the parameters of the samples. The resulting effect ratios were also determined.

Furthermore, the flexural strength was estimated through ANOVA and compared to the determined optimal values at a 95 % confidence level. The mathematical model for the flexural strength was derived using regression analysis.

Flexural Strength (MPa) = - 7.15 + 2.632 (Estimated Flexural Strength (MPa)) - 0.0931 (Estimated Flexural Strength (MPa))^2

5.3. Analysis of Abrasion Test Results

S/N ratios were determined for each trial using the obtained abrasion measurements. Table 18 displays the average S/N ratios for each parameter level.(Table 19)

As the longevity of the concrete road is inextricably linked to its minimal abrasion and tear, it is imperative to keep the level of abrasion as low as possible. In the analysis, it is observed that the water/binder ratio at the 2nd level exhibits the lowest S/N average value. Therefore, it can be concluded that the water to binder ratio is the primary contributing factor affecting abrasion. The Signal-to-Noise ratios in Table 18 were assessed based on the lower-is-better characteristic. The figure also displays the resulting optimal blend ratios. The optimal mixture ratios for abrasion are therefore: 2nd level for water/binder ratio, 4th level for fly ash, 2nd level for nano Fe_2O_3, 1st level for nano TiO_2 and 2nd level for basalt fiber.

A variance analysis was conducted to ascertain the impact of the abrasion test results applied to the specimens on the parameters, and the effect ratios were determined.

In addition, abrasion resistance was estimated by ANOVA and compared with the optimum values determined at a 95 % confidence level. Based on the regression analysis conducted, the mathematical model for abrasion resistance is as follows;

Amount of Abrasion (g) = - 0.8410 + 1.679 (Estimated Amount of Abrasion (g)) - 0.1328 (Estimated Amount of Abrasion (g)) ^{2}

5.4. Analysis of Verification Test Results

In the second stage, three separate compound calculations were made for the optimum ratios found in the compression, flexure and abrasion tests. Three different mixes were prepared according to these optimum mix calculations. The dosages of materials used in the mixtures per 1 m^3 are given in the Table 20.(Tables 21–26)

After the prepared mixtures had been left to cure for 28 days, the samples underwent compression, flexure and abrasion tests. The optimal values were then assessed individually and the optimal mixture was identified. Upon examination of the test results, it becomes apparent that the abrasion test yields better optimal results compared to the flexure and compression tests. Based on the optimum outcomes of the compressive strength test, the mean performance metric, S/N ratio, was determined to be 34.47. The predicted compressive strength value under ideal circumstances is 53.06 MPa. Based on the results of the verification experiments, the optimal compressive strength value of 61.2 MPa was achieved in the third mixture. The S/N at this value measures 35.61. Based on the 95 % confidence interval, the expected S/N ratio falls between 33.04 and 35.7. The findings indicate that the compressive strength measure

Table 14
Compressive Strength S/N Ratios.

Group Number	Compressive Strength (MPa)	S/N
1	54.27	34.69
2	44.18	32.91
3	34.84	30.84
4	36.92	31,34
5	26.66	28.52
6	63.66	36.08
7	19.22	25.68
8	59.30	35.46
9	60,19	35.59
10	61.34	35.75
11	63.76	36.09
12	60.25	35.60
13	61.46	35.77
14	61.76	35.81
15	58.59	35,36
16	59.10	35.43
Average S/N		33.81

Table 15
Effect Rates of Parameters on Compressive Strength.

Parameter	Degrees Of Freedom	Sum Of Squares	Impact Rate
Water/Cement	3	1360.6	43.46 %
Fly Ash	3	400.1	12.78 %
Nano Fe_2O_3	3	577.5	18.45 %
Nano TiO_2	3	345.6	11.04 %
Basalt Fiber	3	446.6	14.27 %
Total	15	3130.4	100 %

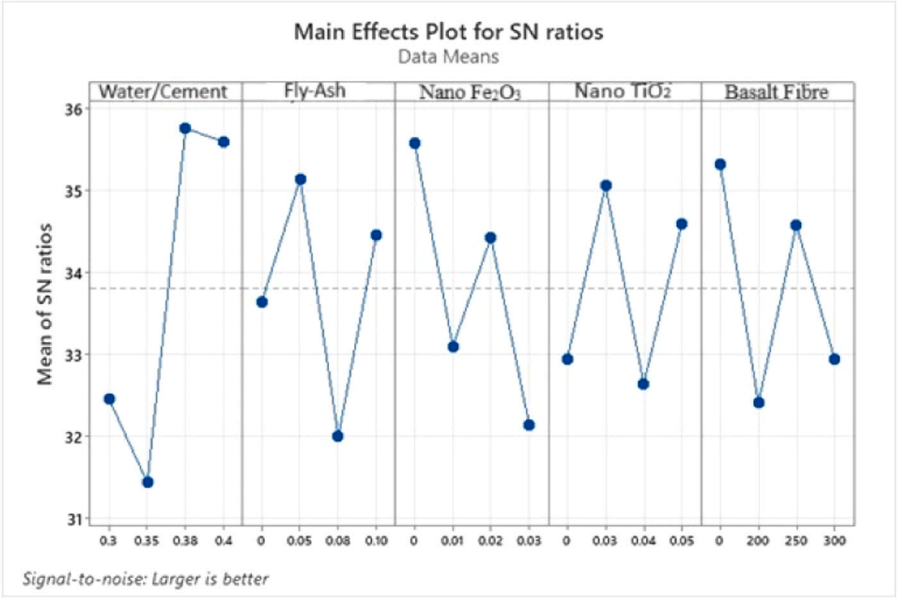

Fig. 8. S/N Ratios According to Compressive Strength.

of the verification sample falls within the confidence range, thus providing high reliability for the optimal outcome.

Based on the optimal outcomes of the flexural strength test, the average performance statistic, S/N ratio, was found to be 18.91. The expected flexural strength under optimum conditions is 8.82 MPa. Based on the verification tests, the optimal flexural strength value of 8.8 MPa was obtained in the third compound. The S/N ratio for this value is 18.86. The 95 % confidence interval predicts the S/N ratio to fall between 17.86 and 18.92. The findings indicate that the flexural strength measurement of the verification sample falls within the

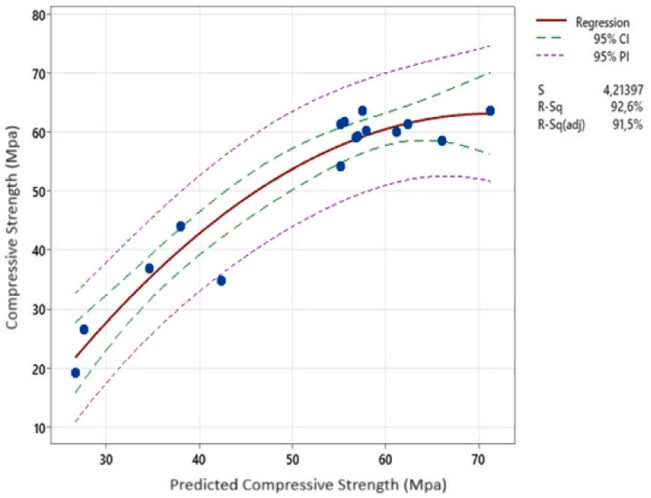

Fig. 9. Regression Model for Predicted Pressure Value.

Table 16
Flexural Strength S/N Ratios.

Group Number	Flexural Strength	S/N
1	8.90	18.99
2	8.40	18.49
3	8.44	18.53
4	8.74	18.83
5	9.20	19.28
6	8.33	18.41
7	9.06	19.14
8	9.21	19.28
9	8.93	19.01
10	9.01	19.09
11	8.86	18.95
12	9.03	19.11
13	8.83	18.92
14	8.96	19.05
15	8.76	18.85
16	8.53	18.62
Average S/N		18.91

Table 17
Effect Rates of Parameters on Flexural Strength.

Parameter	Degrees Of Freedom	Sum Of Squares	Impact Rate
Water/Cement	3	0.1856	16.54 %
Fly Ash	3	0.1871	16.67 %
Nano Fe_2O_3	3	0.1584	14.12 %
Nano TiO_2	3	0.3061	27.28 %
Basalt Fiber	3	0.2849	25.39 %
Total	15	1.1221	100 %

confidence interval, thus validating the reliability of the optimal outcome.

Finally, upon examining the optimal outcomes for the abrasion test, the average performance statistic, the signal-to-noise ratio, was found to be −7.92. The abrasion amount that is estimated under optimum conditions is 2.53 g. Upon analyzing the verification experiments, it becomes evident that the third mixture demonstrated the lowest amount of abrasion (2.46 g). The S/N ratio for this value is −6.99. According to the 95 % confidence interval, the signal-to-noise ratio is expected to be in the range (-7.89) -(−6.11). The results demonstrate that the abrasion value of the verification sample remains within the confidence interval, so the reliability of the optimum result is high.

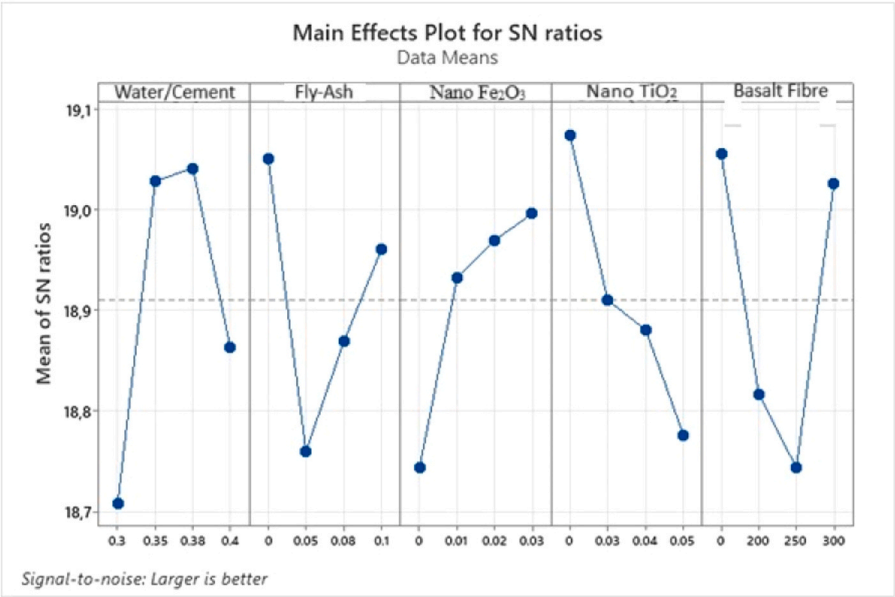

Fig. 10. S/N Ratios According To Flexural Strength.

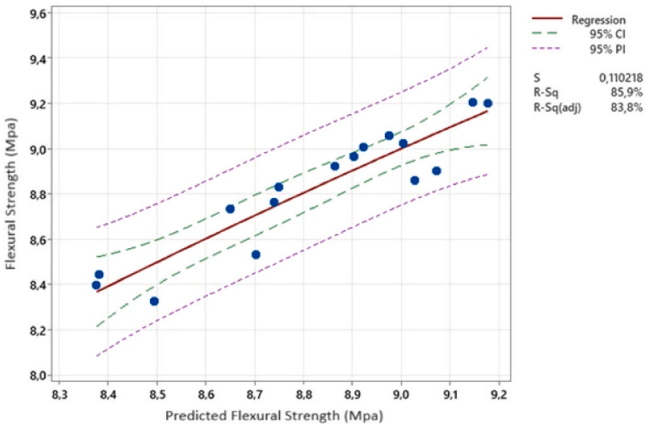

Fig. 11. Regression Model for Estimated Flexural Value.

6. Conclusion

A calculation for a high-strength RCC mixture for road construction was designed in this study using nano powder, fly ash and basalt fiber. In the initial phase of the study, the pressure, bending and wear resistance of the mixtures prepared in accordance with the L16 orthogonal array were subjected to testing in the Taguchi experimental design. The initial testing yielded three optimal mixture calculations. The results of the optimal mixture calculations were subjected to confirmation experiments, and the reliability of the study was tested statistically using ANOVA. In the second stage of the study, the three mixture calculations that emerged in the first stage were designated as Mixture-1, Mixture-2, and Mixture-3. Verification samples were prepared and subjected to the same tests as the original samples. Following the implement of the tests, the S/N ratios were determined in accordance with the Taguchi method, and it was established that the tests remained within the confidence range. In the final stage of the study, the resulting strength values were compared with other studies and specifications in the literature.

The following section presents the inferences and discussions made.

-In consideration of the specified pressure and flexural values outlined in the Concrete Road Pavement Technical Specification of the General Directorate of Highways [40], it can be concluded that the compressive strength of conventional concrete is expected to be a minimum of 37 MPa, while the flexural strength is expected to be a minimum of 4.5 MPa. When examining the results of the verification experiment, it is clearly evident that the experimental results of the third mixture identified as the optimum mixture significantly exceed the values specified in the specifications. It can therefore be concluded that RCC reinforced with nano powder and

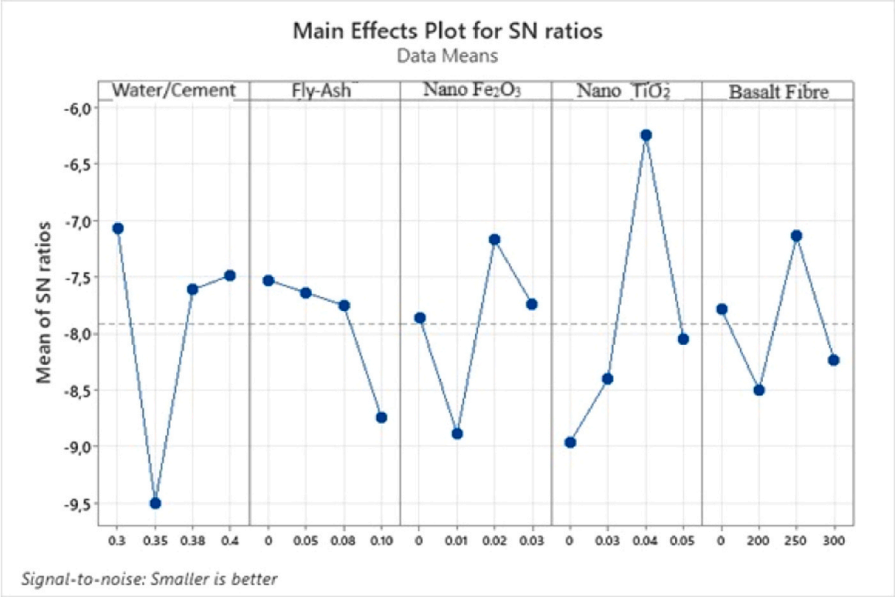

Fig. 12. S/N Ratios According To Abrasion Losses.

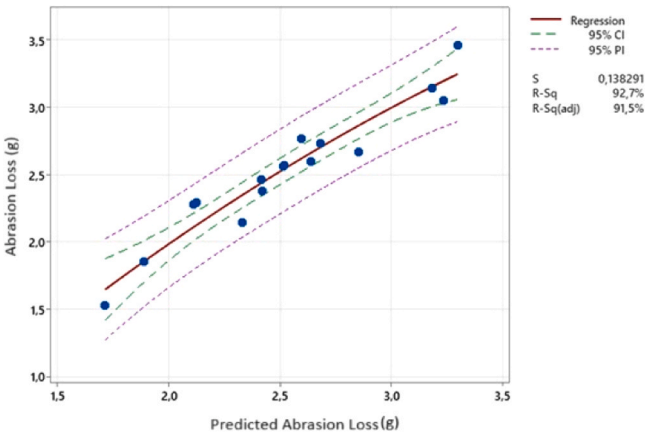

Fig. 13. Regression Model for Predicted Abrasion Loss Value.

fibers exhibits superior strength to traditional concrete. The impact of the nano- and fibrous materials incorporated into the concrete on its strength was also investigated.

-When the literature was examined, Bilim determined in his study that nano TiO_2 affected the compressive strength to a small extent and did not contribute to the flexural strength and made suggestions to determine how the use of nano TiO_2 would affect the concrete through various experiments [19]. The study, unlike the literature, performed wear experiments and found no significant effect of TiO_2. The high cost of the material may provide an advantage in not using it.

-Çevik aimed to increase the strength of concrete by incorporating basalt fibers in his study. The study found that the basalt fiber mixture had a compressive strength of 35.73 MPa and a flexural strength of 6.53 MPa [21]. In this study the maximum compressive strength was found to be 61.2 MPa and the maximum flexural strength was found to be 8.8 MPa. Therefore, the designed concrete mixture achieved higher values than some studies cited in the literature.

-In a separate study using nano Fe_2O_3 and TiO_2, it was discovered that these materials increased compressive strength by 10.5 % and 11.8 %, respectively. However, no experiments on flexure were carried out [41]. In this study, when the combination of the two materials was used, there was a 4 % decrease in compressive strength. It can be said that the nano TiO_2 that was used was the cause of this decrease. It is thought that if materials other than nano TiO_2 are used in the concrete road to be designed, an effective road concrete can be created. Upon examination of the relevant literature, it is evident that TiO_2 does not typically exert a significant influence on the strength of concrete.

A comparison of the results obtained from the tests and literature comparisons indicates that the third mixture calculation results in

Table 18
Abrasion Losses S/N Ratios.

Group Number	Amount Of Abrasion (g)	S/N
1	2.38	−7.54
2	2.77	−8.84
3	1.53	−3.71
4	2.57	−8.19
5	2.73	−8.73
6	2.67	−8.53
7	3.47	−10.8
8	3.14	−9.95
9	2.29	−7.21
10	1.85	−5.36
11	2.57	−8.20
12	3.05	−9.69
13	2.15	−6.65
14	2.47	−7.84
15	2.60	−8.31
16	2.28	−7.17
Average S/N		−7.92

Table 19
Effect Rates of Parameters on Abrasion Resistance.

Parameter	Degrees Of Freedom	Sum Of Squares	Impact Rate
Water/Cement	3	1.21	35.74 %
Fly Ash	3	0.33	9.62 %
Nano Fe2O3	3	0.40	11.71 %
Nano TiO_2	3	1.19	35.16 %
Basalt Fiber	3	0.26	7.77 %
Total	15	3.39	100 %

Table 20
Verification Test Materials Dosages.

Mixture No.	**Cement (kg)**	**Fly Ash (kg)**	**Nano Fe_2O_3 (kg)**	**Nano TiO_2 (kg)**	**Basalt Fiber (kg/m^3)**
Mixture−1	322	17.5	0	10.5	0
Mixture−2	339.5	0	10.5	0	0
Mixture−3	329	0	7	14	2.5

Table 21
Compressive Strength of Verification Samples.

Compressive Strength (MPa)				
Mixture No.	**1. Sample**	**2. Sample**	**3. Sample**	**Average**
Mixture−1	33.81	43.32	29.25	35.46
Mixture−2	48.77	37.33	51.54	45.88
Mixture−3	60.69	58.45	64.47	61.20

Table 22
Compressive Strength Performance Values of Verification Samples.

Parameters	Level	Contribution to S/ N
Water/Cement	S3	2.36
Fly Ash	S2	0.69
Nano Fe_2o_3	S1	0.65
Nano Tio_2	S2	0.6
Basalt Fiber	S1	0.77
Contribution Of All Factors (S/N)	5.07	
Average Performance Statistics (S/N)	34.47	
Expected Value Under Optimum Conditions (MPa)	53.06	
Verification Test Result (S/ N)/ (MPa)	35.61 / 61.2	
Confidence Interval (S/N)	33.04–35.7	

Table 23
Flexural Strengths of Verification Specimens.

FLEXURAL STRENGTH (MPA)				
Mixture No.	**1. Sample**	**2. Sample**	**3. Sample**	**Average**
Mixture−1	7.09	7.37	7.28	7.25
Mixture−2	6.67	7.25	6.92	6.95
Mixture−3	8.74	8.91	8.75	8.80

Table 24
Flexural Strength Performance Values of Validation Samples.

PARAMETERS	LEVEL	CONTRIBUTION TO S/ N
Water/Cement	S3	0.19
Fly Ash	S1	0.19
Nano FE_2O_3	S4	0.16
Nano TIO_2	S1	0.31
Basalt Fıber	S1	0.28
Contribition Of All Factors (S/N)	1.12	
Average Performance Statistics (S/N)	18.91	
Expected Value Under Optimum Conditions (MPa)	8.82	
Verification Test Result (S/ N)/ (MPa)	18.86/8.8	
Confidence Interval (S/N)	17.86–18.92	

Table 25
Abrasion Losses.

	Before The Experiment (g)			**After The Experiment (g)**			**Difference (g)**		
Mixture No.	**1. Sample**	**2. Sample**	**3. Sample**	**1. Sample**	**2. Sample**	**3. Sample**	**1. Sample**	**2. Sample**	**3. Sample**
Mixture−1	835.4	803.4	820.7	830.9	800	816.8	4.5	3.4	3.9
Mixture−2	781.5	750.8	706.7	777.9	747.9	703.5	3.6	2.9	3.2
Mixture−3	759.1	729.5	736.8	756.7	726.7	734.6	2.4	2.8	2.2

Table 26
Abrasion Loss Performance Values of Validation Samples.

PARAMETERS	LEVEL	CONTRIBUTION TO S/ N
Water/Cement	2	1.21
Fly Ash	4	0.33
Nano FE_2O_3	2	0.40
Nano TIO_2	1	1.19
Basalt Fiber	2	0.26
Contribition Of All Factors (S/N)	3.39	
Average Performance Statistics (S/N)	−7.92	
Expected Value Under Optimum Conditions (g)	2.53	
Verification Test Result (S/ N)/ (g)	−6.99/2.46	
Confidence Interval (S/N)	−7.89-/−6.11	

the greatest increase in strength compared to other optimum mixture calculations. It can be stated that the third mixture prepared within the scope of the study did not include the use of nano-TiO_2 material. Upon examination of other mixtures, it was found that the incorporation of nano-TiO_2 did not result in any discernible enhancement in compression, bending, or wear resistance. Therefore, the use of nano TiO_2 in road concrete is not expected to have a positive effect on the road.

Consequently, it is anticipated that the RCC road constructed in accordance with the third mixture calculation will exhibit enhanced resistance to pressure, flexural, and abrasion forces compared to traditional concrete. It is possible that the initial costs of the RCC road design will be high due to the price of the nanomaterial used. However, it is worth noting that the designed RCC road is highly resistant to abrasion, pressure, and flexural caused by wheel loads, making maintenance and repair costs almost negligible.

The following studies are recommended for future investigation:

-More cost-effective and sustainable concrete road designs can be achieved by reducing the use of nano materials. Furthermore, more durable RCC roads can be constructed by conducting various tests to determine the optimal mixture calculations and other mechanical and physical properties of the concrete.

-The effect of varying the ratio of TiO_2 on the mechanical properties of concrete can also be examined.

-In this study, concrete mixture calculations were made with consideration of the zero slump of RCC. In future studies, it may be

recommended to conduct slab tests, optimum compression ratio, moisture content, ultrasound transmission speed experiments for the RCC road designed with the optimum values found in this study.

-In order to ascertain the impact of basalt fiber on concrete in other ways, experiments can be conducted to assess abrasion, ultrasonic pulse velocity and capillary water absorption.

-It is recommended that the properties of the constructed road be examined by applying the determined optimum mixture values in the field.

CRediT authorship contribution statement

Ahmet TORTUM: Writing – review & editing, Visualization, Supervision, Software, Methodology, Formal analysis. **Şeyma Sünbül:** Writing – original draft, Resources, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This study was prepared within the scope of the Scientific Research Project of Atatürk University, Türkiye, ID 11012.

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