Research Article

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Evaluation of the Efficiency of Different Waterproofing Products in Concrete for Sustainability

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ABSTRACT

The efficacy of several waterproofing products in concrete, such as integrated waterproofing compound, water-repellent cement and waterproofing coatings with acrylic and styrene-butadiene latex co-polymer bases was assessed in this experimental study. The mechanical properties, durability and fresh concrete parameters were examined and a comparison was related to control concrete-concrete that had not been treated with any waterproofing compound. Concrete with an integrated waterproofing chemical exhibited the largest slump of 56 mm, whereas the concrete with water-repellent cement displayed the highest density of 2459 kg/m^3. Concrete with integral waterproofing chemical showed the best compressive strength of 39.33 N/mm^2, flexural strength of 5.85 N/mm^2 and split-tensile strength of 3.80 N/mm^2, respectively, at 28 days. Cube specimens treated with an acrylic base water-proofing coating showed a minimum average rate of water absorption of 0.36 and a minimum sorptivity of 0.022 mm/min$^{0.5}$, after 48 hours. It was concluded that the best result for mechanical properties was shown by concrete with an integral waterproofing compound, whereas the concrete with acrylic-based waterproofing coating was the best performer in terms of durability parameters.

Keywords: Waterproofing; Strength; Absorption; Sorptivity; Sustainability.

1. INTRODUCTION

Being a porous material, concrete deteriorates when exposed to outside conditions, shortening the structure's lifespan (Omale and Oguntade, 2022). It is anticipated that the annual cost of repairing concrete structures damaged by water or water-borne pollutants approaches billions of dollars (Azarsa *et al.* 2019). Waterproofing is essential for maintaining concrete structures and extending their useful lifespans. Waterproofing compounds are used primarily to stop the ingress of water into the concrete (Cho *et al.* 2019). Waterproofing can be characterized as the development of an inner or outer film, fit for keeping water from entering or getting away through a porous layer (Arulinfanta *et al.* 2019). There are many different means to provide internal or external membranes in the construction industry. Waterproofing admixtures are added to the concrete as it is being mixed to provide internal membranes (Jahandari *et al.* 2023). Applying liquid coatings and sheet membranes on the surface of concrete provides external membranes (Sriravindrarajah and Tran, 2018). Enhancing the pore structure through waterproofing as well as providing the steel with a water-resistant environment prolongs the lifespan of the structure (Tan *et al.* 2023). Moisture in concrete gives mosquitoes a place to nest, which increases the growth of pathogenic microorganisms (Khezzani *et al.* 2023). Thus, the danger of contracting illnesses by Zika virus, malaria, West Nile virus, dengue fever, yellow fever, chikungunya and other illnesses spread by mosquitoes is greatly increased (Khezzani *et al.* 2023). Numerous epidemiological investigations have demonstrated connections between moisture and detrimental health consequences (Udofia *et al.* 2014). To keep concrete nearly dry and lessen the harmful effects of moisture on human health, waterproofing works to reduce the permeability of water and moisture transmission (Jalal *et al.* 2018). Concrete waterproofing improves indoor air quality and reduces the need for regular building maintenance and repairs. By adopting waterproofing materials, the structures' aesthetic appeal might also be preserved for an even greater amount of time (Gomes *et al.* 2023).

The environmental sustainability of waterproofing compounds has been subject to evaluation through various studies. The environmental effects of waterproofing procedures have been examined using Life Cycle Assessment (LCA) techniques. The need for sustainable solutions is highlighted by the fact that conventional methods have lesser environmental implications than waterproofing techniques (Baquero *et al.* 2021). Recognized for their sustainability, crystalline waterproofing systems offer practical, affordable and user-friendly solutions. Furthermore, the costs of different waterproofing techniques such as sheet, asphalt and membrane waterproofing have been evaluated using sustainability life cycle cost studies (Kim *et al.* 2013). Studies have also been conducted to investigate the environmental compatibility of bitumen waterproofing, taking into account the possibility of hazardous chemical leaching (Vollpracht and Brameshuber, 2013).

2. MATERIALS USED

Different types of materials used in this experimental investigation are discussed below:

2.1 CEMENT AS BINDER

In accordance with the Indian standards **(IS 1489 (Part 1) - 1991)**, Portland Pozzolana Cement (PPC) was used as the binder in the preparation of concrete mixtures excluding the mixtures containing water-repellent cement. Table 1 displays the cement binder's characteristics.

Table 1. Characteristics of PPC

S. No.	Characteristics	Value
1	Specific Gravity	2.67
2	Normal Consistency	31.5%
3	Initial setting time	169 min.
4	Final setting time	220 min.
5	Color	Grey

2.2 WATER-REPELLENT CEMENT

In accordance with the Indian standards **(IS 8043 –1991)**, hydrophobic cement was used as the binder in the preparation of one of the mixes. Table 2 displays the cement binder's characteristics.

Table 2. Characteristics of water-repellent cement

S. No.	Characteristics	Value
1	Specific Gravity	2.66
2	Normal Consistency	30.5%
3	Initial setting time	150 min.
4	Final setting time	200 min.
5	Color	Grey

2.3 FINE AGGREGATE

Locally available natural sand passing through a 4.75 mm IS sieve was used as fine aggregate. For determining the fineness modulus and zone of the river sand, sieve analysis was performed according to the Indian Standards **(IS: 383-1970)**. The properties of sand were determined by conducting tests as per the Indian standards **(IS: 2386 (Part- I)).** Table 3 represents the characteristics of these fine aggregates.

2.4 COARSE AGGREGATES

Locally available coarse aggregates of two different sizes passing through 20 mm and 12.5 mm IS sieves were used for the experimental work. Sieve analysis of the coarse aggregates was done to determine the fineness modulus. The Pycnometer Test was used to assess the specific gravity. Table 4 indicates the characteristics of these aggregates. Throughout the entire experimental study, the proportions of 20 mm and 10 mm aggregates were taken to be 60% and 40%, respectively.

Table 3. Characteristics of fine aggregate

S. No.	Characteristics	Value
1	Fineness modulus	2.4
2	Specific Gravity	2.54
3	Grading Zone	Zone III
4	Water Absorption	1.6%

Table 4. Characteristics of coarse aggregate

Properties	Coarse Aggregates	
	20 mm	10 mm
Fineness modulus	8.21	7.8
Specific Gravity	2.61	2.74
Water Absorption	0.56%	0.40%

2.5 WATER

Potable water, free from salt, was used for casting and curing concrete, as per the recommendations of the Indian Standards (**IS: 456 – 2000**).

2.6 WATERPROOFING COMPOUNDS

Two types of waterproofing compounds including an integral water-proofer and two waterproofing coatings were used in this experimental investigation.

2.6.1 Integral Water Proofer

A commercially available integral waterproofing compound was used.

2.6.2 Waterproofing Coatings

Two types of coatings were used: Acrylic-based elastomeric waterproofing coating and Styrene Butadiene Latex co-polymer.

Table 5. Ingredients and the mix proportion of 1 m^3 concrete

Ingredient	Quantity	w/c ratio	Mix Proportion
Cement	410 kg	0.45	1:1.22:2.97
Fine aggregate	500 kg		
Coarse aggregate	1217 kg		
Water	184.5 kg		

3. METHODS

3.1 CONCRETE MIX DESIGN

The concrete mix was designed as per **(IS 10262 – 2009)** for the normal concrete. M_{25} grade of concrete with a mix proportion of 1:1.22:2.97, w/c ratio of 0.45

and a cement quantity of 410 kg/m^3 was used. The quantity of the ingredients and the mix proportion obtained after the design mix is given in Table 5.

3.2 SPECIMEN CASTING

The laboratory-prepared concrete was investigated for calculation of slump, fresh concrete density, compressive strength, split-tensile strength, flexural strength, water absorption and sorptivity. The nomenclature of various mixes was done according to the chemicals employed in it. The specimens made with different compounds are designated as control category (CC), integral water-proofer (IWC), water repellent cement (WRC), acrylic-based coating (C1) and Styrene butadiene latex co-polymer waterproofing coating (C2).

4. RESULTS AND DISCUSSION

4.1 WORKABILITY

The workability of concrete was determined with the slump cone test as per (**IS: 1199-1959**). The ease or difficulty of handling, transporting and placing concrete between the forms with the least amount of homogeneity loss is referred to as workability **(Shetty and Jain, 2019)**. Fig. 1 is the pictorial representation of the slump values of all the mixes.

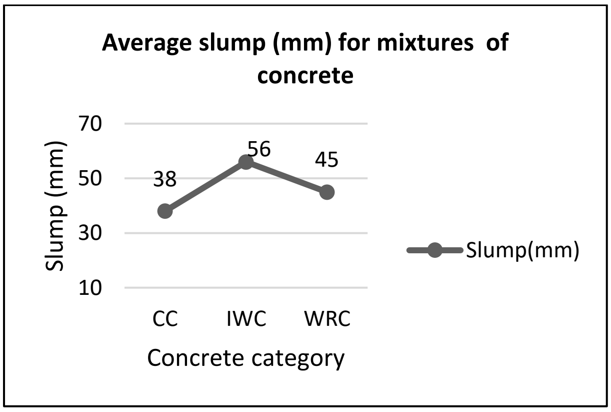

Fig. 1: Slump test results

The data clearly shows that the slump is higher in mixes of concrete containing waterproofing materials. Among all the mixes, concrete with integral waterproofing chemical has the highest slump value.

4.2 DENSITY OF FRESH CONCRETE

The density of fresh concrete was measured by putting the concrete in a container of known volume and then calculating the density from the mass measured. The fresh concrete densities of different mixes of concrete are pictorially presented in Fig. 2.

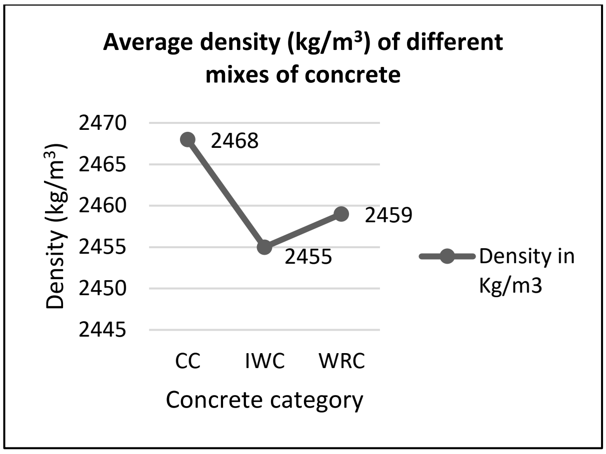

Fig. 1: Fresh density of various categories of concrete

It is observed that there is no marginal difference between the fresh densities of various mixtures of concrete.

4.3 COMPRESSIVE STRENGTH

The tests were conducted on cube specimens of size 150 mm after 7 and 28 days of curing. The testing was done as per the Indian Standards (**IS: 516-1959**). The results obtained are as shown in Fig. 3.

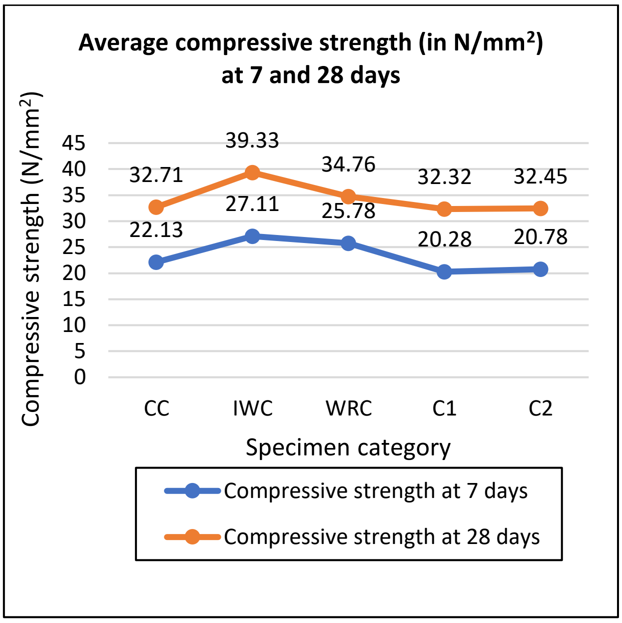

Fig. 3: Average compressive strength at 7 and 28 days

On comparing 7 days compressive strength after 7 days with control, IWC and WRC mixes showed a strength increase of 22.5% and 16.49% respectively, whereas a decrease of 8.46% and 6.10% was recorded in C1 and C2 mixes respectively.

Compressive test results at 28 days revealed that the highest strength was shown by IWC with an increase in strength by 20.24%, followed by WRC which had attained a strength 6.27% greater than the referral category. The minimum strength was shown by C1 which showed a decrease in strength by 1.19%. C2 had attained a compressive strength 0.8% less than CC.

4.4 SPLIT TENSILE STRENGTH

Split tensile test was performed on cubes of 150 mm size by splitting the cubes along one of the diagonal planes by applying compressive forces along two opposite edges, as shown in Fig. 4 **(Gambhir, 2013).**

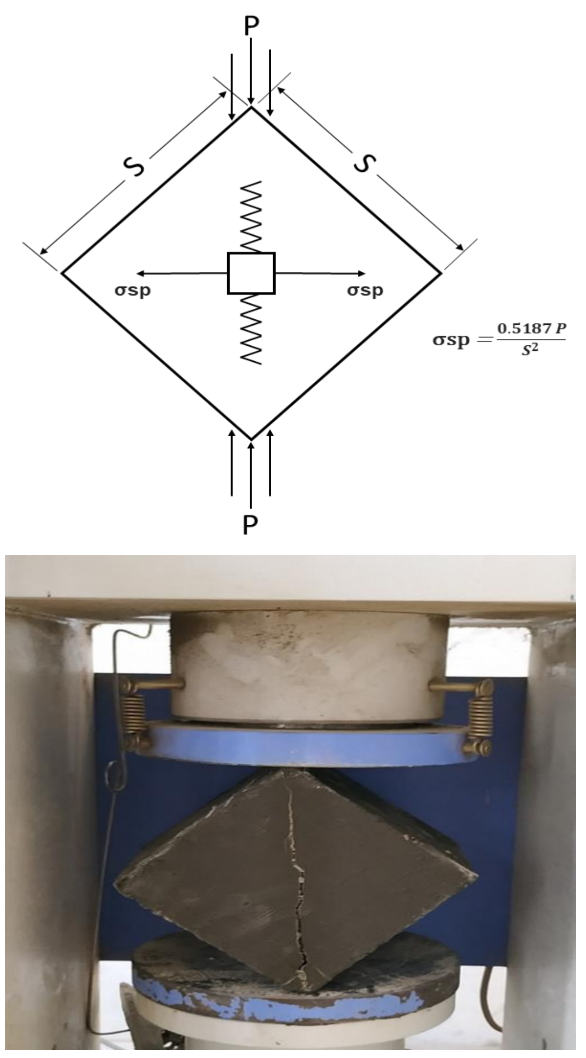

Fig. 4: Compressive forces along two opposite edges

The split tensile strength is determined by,

$$f_{ct} = 0.5187\ P/S^2$$

where,

f_{ct} = Split tensile strength

P = Failure load

S = Side of the cube

The values obtained from the experimental investigation are shown in Fig. 5.

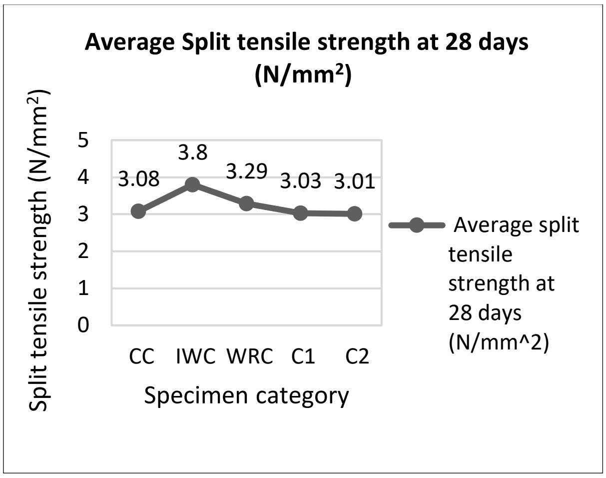

Fig. 2: Average Split tensile strength at 28 days (N/mm²)

CC showed an average split tensile strength of 3.08 N/mm². The increase in split tensile strength of IWC was 23.37%, as compared to CC which is the maximum among the groups. The maximum decrease of 2.27% was shown by C2 which is the minimum of all groups. WRC showed an increase of 6.8%, whereas C1 showed a decrease of 1.62% in split tensile strength, compared to CC.

4.5 FLEXURAL STRENGTH

Flexural strength test was conducted after 28 days of curing as per the Indian standards **(IS: 516 – 1959)** on 100 mm × 100 mm × 500 mm prisms. The values obtained from the experimental investigation are given in Fig. 6.

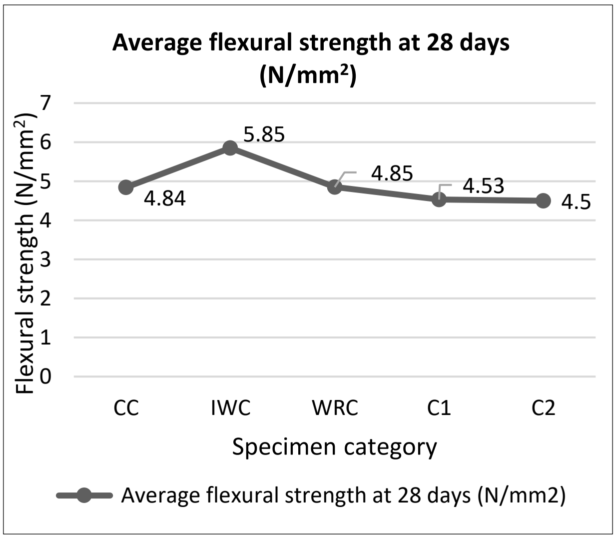

Fig. 6: Average flexural strength at 28 days

Referral concrete (CC) had attained a flexural strength of 4.84 N/mm^2. On comparing all mixes with CC, an increase in flexural strength of 20.86% was shown by IWC, followed by WRC with an increase of 0.21%; C2 showed a decrease of 7.02%, followed by C1 with a decrease of 6.40%.

4.6 WATER ABSORPTION

The water absorption was determined in accordance with American Society for Testing and Materials (**ASTM C 642)** using concrete cube specimens of dimension 150 mm. These specimens were oven-dried followed by cooling and were then immersed in water for a period of 48 h. The results obtained from the water absorption results are given in Fig. 7.

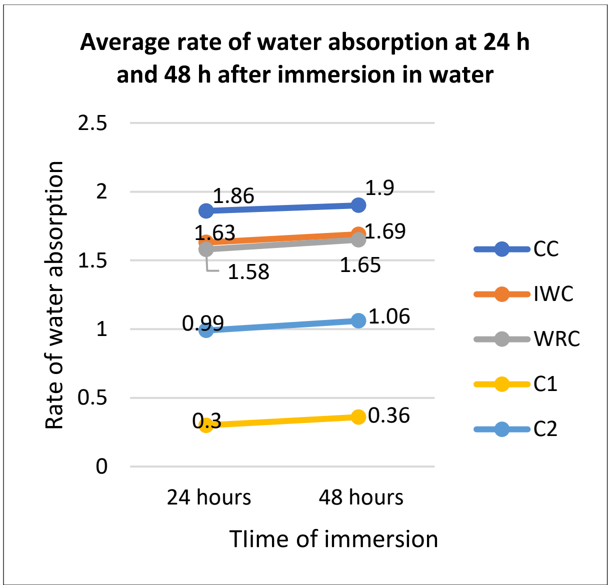

Fig. 7: Average rate of water absorption after 24 h and 48 h of immersion

After 24 h of immersion in water, C1 showed a minimum water absorption rate of 0.3, followed by C2 (0.99). The referral group (CC) showed a maximum water absorption rate of 1.86, followed by IWC and WRC with 1.63 and 1.58, respectively.

After 48 h of immersion, the maximum decrease in water absorption rate was shown by C1 (81.05%) followed by C2 (44.21%). IWC showed a minimum decrease in water absorption rate at 11.05%, followed by WRC (13.15%).

4.7 SORPTIVITY

Sorptivity determines the rate of penetration of water into pores in concrete by capillary action. The sorptivity test was conducted as per **(ASTM C 642-82)** on cube of 150 mm in this study. Fig. 8 below shows the schematic procedure for sorptivity.

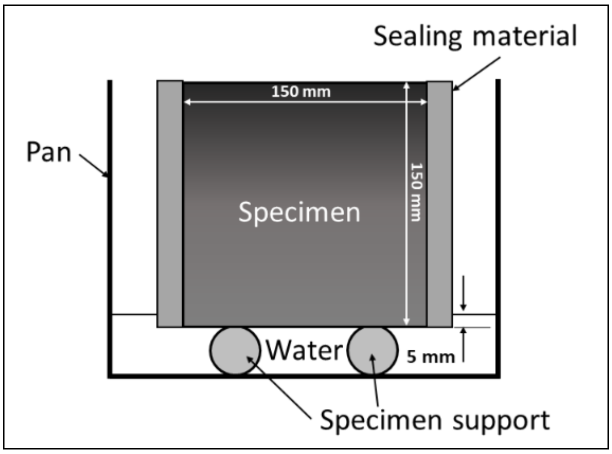

Fig. 8: Schematic procedure for sorptivity

The cubes were immersed in the water; a minimum depth of immersion of 5 mm above the base of the cube was maintained. The interval of calculation of mass gain was 0.5, 1, 1.5 and 2 h and the values calculated are shown in Fig. 9.

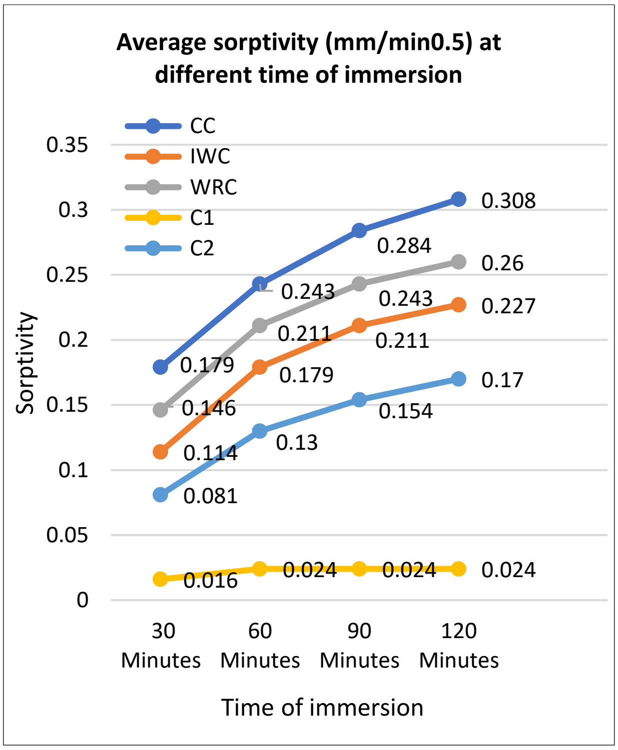

Fig. 9: Average sorptivity ($mm/min^{0.5}$) *vs.* Time of immersion

The average sorptivity for all mixes obtained for a period of 2 h is depicted in Fig. 10.

Among all the specimen categories, the maximum sorptivity was exhibited by CC and the minimum sorptivity by C1. C1 showed a decrease of 91.34% in sorptivity, as compared to CC. The other specimen categories - IWC, WRC and C2 showed a decrease of 27.95%, 15.35% and 47.24% in sorptivity, as compared to CC.

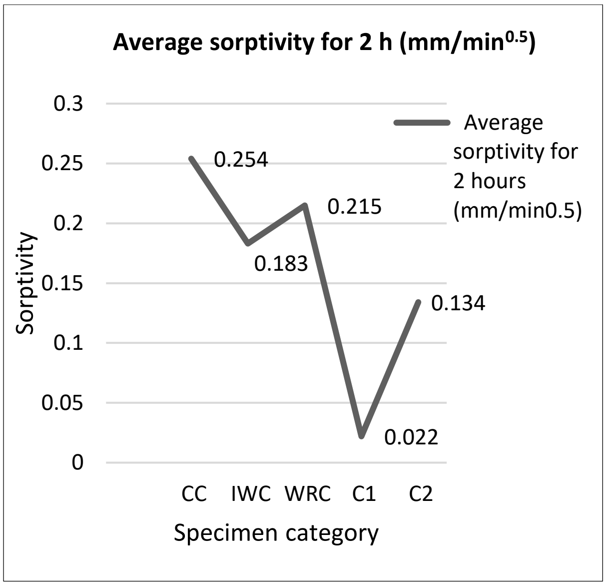

Fig. 10: Average sorptivity for 2 h

5. DATA ANALYSIS

Statistical models of the relationship between dependent variable (response variable) and independent variable (explanatory variable) can be developed using linear regression.

5.1 RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND FLEXURAL STRENGTH

Linear regression using MS Excel was used to establish a relationship between compressive strength and flexural strength; the relationship developed is,

$y = 0.1787x - 1.2176$ …………………… (Equation-1)

where,

y = Average flexural strength at 28 days

x = Average compressive strength at 28 days

The coefficient of determination, obtained from the relation was 0.9379.

Table 6. Observed and predicted flexural strengths

Flexural strength (N/mm^2) at 28 days		Error (%)
Observed	Predicted	
4.84	4.78	1.30
5.85	5.76	1.57
4.85	5.08	-4.76
4.53	4.72	-4.18
4.50	4.72	-4.87

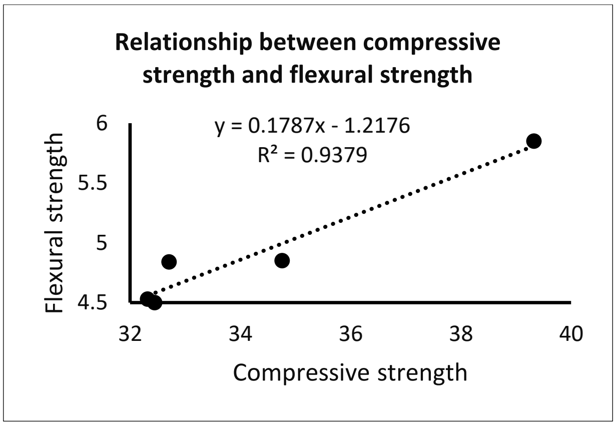

Fig. 11: Relationship between compressive strength and flexural strength

The observed and the predicted flexural strength for 28 days with the percentage error for these two data types is presented in Table 6.

A plot between the observed and predicted flexural strength is shown in Fig. 12.

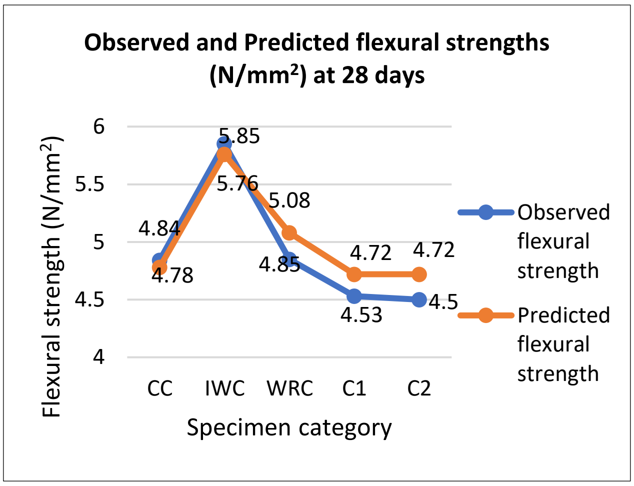

Fig. 12: Graph between observed and predicted flexural strengths

5.2 RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND SPLIT TENSILE STRENGTH

Data of compressive strength was used as an independent variable and the data of split tensile strength was used as a dependent variable. The relationship developed is,

$y = 0.1112x - 0.5745$ …………….. (Equation-2)

where,

y is split tensile strength at 28 days

x is compressive strength at 28 days

The coefficient of determination obtained from the relation was 0.9978. The relationship between compressive strength and split tensile strength is shown in Fig. 13.

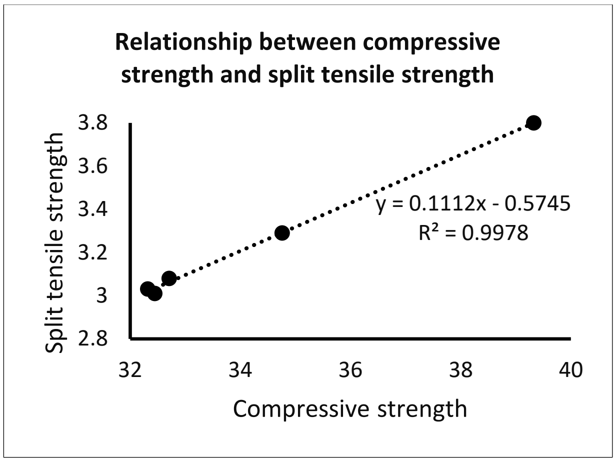

Fig. 13: Relationship between compressive strength and split tensile strength

Equation 2 is used to predict the split tensile strength of different concrete mixes and the percentage error for the prediction. The observed and predicted split tensile strength is presented in Table 7 and plotted in Fig. 14.

Table 7. Observed and predicted split tensile strengths

Split tensile strength (N/mm^2) at 28 days		Error (%)
Observed	Predicted	
3.08	3.06	0.56
3.80	3.80	0.03
3.29	3.29	-0.02
3.03	3.02	0.35
3.01	3.02	-0.32

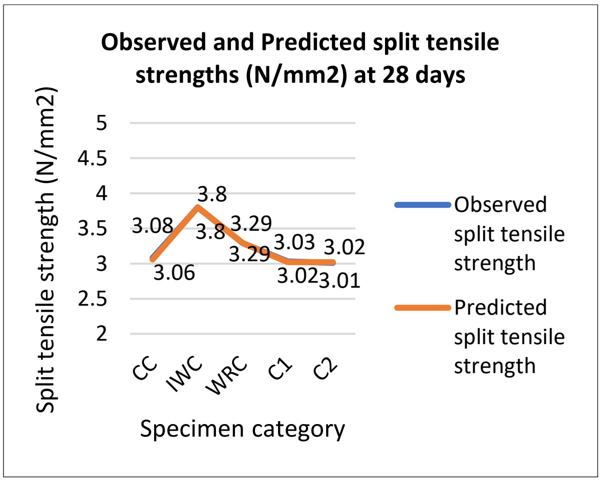

Fig. 14: Graph between observed and predicted split tensile strengths

6. CONCLUSION

From the study carried out, the following conclusions were drawn:

1. A slight decrease in fresh concrete densities of mixes with integral waterproofing compound and water repulsive cement was noticed; on the other hand, it helped in increasing the workability of concrete.

2. Concrete mixes with integral waterproofing compound and water repulsive cement exhibited a better performance in terms of the mechanical properties, in comparison with the referral concrete; however, the mixes with applied coatings have shown a slight decrease in the mechanical properties.

3. After 48 h of immersion, the maximum decrease in water absorption rate was shown by the specimen category of the acrylic-based waterproofing compound at 81.05%, followed by the specimen category of styrene butadiene latex copolymer at 44.21%. The specimen category of integral waterproofing compound has shown a minimum decrease in water absorption rate at 11.05%, followed by the water-repulsive cement at 13.15%.

4. For average sorptivity for 2 h of the specimen category acrylic-based waterproofing coating has shown a decrease of 91.34% in sorptivity. The other specimen categories: integral water-proofer, water-repulsive cement and styrene butadiene latex co-polymer waterproofing coating have shown a decrease of 27.95%, 15.35% and 47.24% in average sorptivity, for 2 h, respectively.

5. When used with caution, waterproofing chemicals are compatible with green construction methods and provide long-term advantages for ecosystems and structures. However, a careful balance must be struck while using such chemicals, to avoid unintended negative effects on the environment. Reducing adverse effects is mostly dependent on sustainable practices and material selection.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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