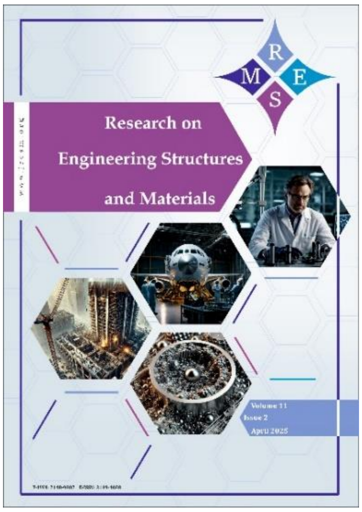
Research on Engineering Structures & Materials

www.jresm.org

Research Group



Effect of de-icing in conductive concrete by varying carbon powder percent and slab thickness

C B Supriya, B H Manjunath, Neeraj S N, Prakash J, Sagar H

Online Publication Date: 10 April 2024

URL: http://www.jresm.org/archive/resm2025-732ma0308rs.html
DOI: http://dx.doi.org/10.17515/resm2025-732ma0308rs

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article
Supriya C B, Manjunath B H, Neeraj S N, Prakash J, Sagar H. Effect of de-icing in conductive concrete by varying carbon powder percent and slab thickness. *Res. Eng. Struct. Mater.*, 2025; 11(3): 1275-1286.

Research on Engineering Structures & Materials
www.jresm.org
Research Group

Research Article

Effect of de-icing in conductive concrete by varying carbon powder percent and slab thickness

C B Supriya [1,a], B H Manjunath [1,b], Neeraj S N [*,2,c], Prakash J [3,d], Sagar H [2,e]

[1]*Dept. of Civil Engineering, Sri Siddhartha Institute of Technology, SSAHE University, Karnataka, India*
[2]*Dept. of Civil Engineering, Jawaharlal Nehru New College of Engineering, Karnataka, India*
[3]*Dept. of Civil engineering, Shridevi Institute of Engineering and Technology, Karnataka, India*

Article Info

Article History:

Received 08 Mar 2025
Accepted 09 Apr 2025

Keywords:

M_{40} Conductive concrete;
De-icing concrete;
Electrical conductivity;
Carbon additives;
Thermal properties

Abstract

Deposition of Ice is observed over the road in cold countries and to the greater thickness during winter seasons. This problem is critical at bridge locations. This necessitates the removal of ice frequently. Manual removal is very difficult and time consuming. These need a process of continuous automatic removal. Conductive concrete when provided at bridge portion will continuously de-ice that portion. This is due to the heat generation because of its relatively high conductivity and electrical resistivity in the conductive concrete. In this study, an attempt is made to prepare conductive concrete in the laboratory and tested for its de-icing performance. M_{40} grade conductive concrete mixes were prepared with varying percentages of carbon content and cube strengths are determined for the same. The rate of de-icing is tested by proper electric supply to the casted conductive concrete slabs of 6 inch and 8 inch thick with varying carbon contents (8%, 10% and 12%) by weight of aggregates in the laboratory. Steel fibers are maintained constant at 2% by weight of aggregate. 10mm diameter TMT bars of Fe-415 were used as electrodes. The strength of concrete at 12% carbon content is 41.1MPa and further increase in carbon content shown decrease in strength (i.e. <40MPa) which is not recommended for highway pavements. The temperature of slab increased with increase in an applied voltage. This study confirmed that, the de-icing process is highly effective in conductive concrete and may eliminate ice clearing by manually.

1. Introduction

The need for innovative remedies to reduce the negative impact of ice and snowfall on pavement surfaces has led to the conductive concrete development. It is a material that utilizes the electrical properties to provide de-icing processes. Conventional methods of de-icing like application of salt will harm the infrastructure as well as environment and reminding the researchers to identify alternatives that increase the thermal or heat performance of concrete. Studies have shown that conductive concrete can effectively mitigate these problems with the use of materials like carbon fibres, which will improve the electrical conductivity and causes the heat generation by electrical resistance [1].

Furthermore, studies spotlighted the importance of configuration and composition of conductive materials in conductive concrete for the applications of de-icing in various constructions. Optimization of conductive fillers proportion can increase the conductive concrete overall performance[2]. In addition, many researchers have stated that the thermal efficiency and mechanical properties of conductive concrete are closely related to their characteristics of

*Corresponding author: snneraj@jnnce.ac.in
[a]orcid.org/0009-0007-9676-7925; [b]orcid.org/0009-0005-0450-1640; [c]orcid.org/0009-0002-9349-0901; [d]orcid.org/0009-0006-0227-7865; [e]orcid.org/0009-0002-0960-4073
DOI: http://dx.doi.org/10.17515/resm2025-732ma0308rs

microstructure [3][1]. This article aims to investigate the production and evaluation of conductive concrete, highlighting its capacity for pavement solutions and chemical treatments and avoiding removal of snow by manually.

The intension of this study is to achieve the following objectives.

- To develop a conductive concrete with varying carbon content (8%, 10%, and 12%).
- To find out the compressive strength of prepared conductive concrete mixes for make sure integrity of structure.
- To evaluate the de-icing performance of conductive concrete under different voltages.

The development of conductive concrete has gathered an attention because of its effective applications in pavements surface de-icing process. Many studies have explained about this material, developed many methodologies and got positive results. This Concrete is the composite material, and it is the ultimate choice for the most structural applications, because of its low cost, easy availability, versatility and essential intended engineering properties. This composite material has an excellent strength properties and durability, but it is a poor conductor of electricity, particularly in dry condition[4]. The mechanical and electrical properties of concrete may have many important applications in different fields like construction industry, military and in other fields[5, 6].

In cold countries during winter seasons ice is deposited all over the road. Clearing the ice from the road becomes inevitable. This problem is much critical at bridge locations, where traffic jam may take place. Manual removal is difficult and time consuming. In such conditions de-icing the Bridge portion is very much essential. This necessitates the need of Conductive concrete, which has relatively high conductivity. In order to produce conductive concrete, certain number of conductive components such as carbon fiber, graphite, steel fibers etc., are added to the conventional concrete, so that its electrical conductivity increases. Here an attempt is made to prepare conductive concrete slabs for pavements and evaluated its efficiency in de-icing [7, 8].

Research on the implementation of conductive concrete for de-icing applications has shown promising results in various studies. A notable example is the application on the Roca Spur Bridge, a 150-foot-long and 36-foot-wide highway bridge over Salt Creek in Lincoln, Nebraska, near U.S. Route 77. This bridge, the first in the world to utilize conductive concrete for de-icing, has demonstrated excellent performance over a five-year period from 2003 to 2008. It has been noted for its energy efficiency and stable electrical conductivity, effectively preventing the accumulation of ice on the bridge deck [9, 10].

Additional studies have explored the composition of conductive concrete, specifically using graphite powder and waste steel fibres to enhance its properties. For example, a mixture containing 5% graphite powder by weight of cement and 15-20% steel fibres by aggregate weight has proven to be effective in de-icing applications[11, 12]. Experimental results indicate that this mixture significantly improves the concrete's conductivity, allowing it to generate sufficient heat for de-icing purposes [7, 13] . Concrete that possesses both electrical and mechanical properties open up various applications in sectors such as the military, electronics, and civil infrastructure [14, 15]. It is particularly effective in electrical heating applications for de-icing highway bridges and airport runways, where maintaining operational surfaces free from ice is critical [16, 17]. Investigations into the effects of different conductive materials, such as steel fibres and graphite powder, have revealed that increasing the graphite content enhances the concrete's conductivity, although it may slightly reduce its structural strength[18, 19]. For example, a mixture with steel fibres at 8.5% by weight and incremental graphite powder additions ranging from 5% to 20% showed that conductivity improved with increased graphite, but this was accompanied by a decrease in strength [20, 21]. Furthermore, the electrical and thermal properties of conductive concrete have been examined with varying graphite percentages, specimen dimensions, and applied voltages[22]. It has been found that increasing the voltage reduces electrical resistivity while increasing the heat generated in the concrete [23]. Smaller specimen sizes tend to produce higher electrical currents and temperatures, indicating that the amount of graphite, the applied voltage, and the size of the specimen significantly impact the thermal and electrical performance of the concrete[24]. Optimal electrical and thermal properties are achieved with 2% steel and 10% graphite powder in the concrete mixture [25].

The literature review has indicated that, thermal and electrical properties can be improved by making the conventional concrete into conductive concrete and it has many applications, de-icing is one among them. Electrical conductivity leads to the de-icing [26]. Roca Bridge successfully implemented the conductive concrete for de-icing. Here an attempt is made to prepare conductive concrete in the laboratory and tested for its de-icing performance [27, 28]. However, many investigations have shown the application of carbon-based fillers materials such as carbon fibre and graphite in conductive concrete materials, concentrating on improvement of electrical conductivity and mechanical properties, these investigations still leave many gaps. For example, the conductive concrete long-term durability in different environmental conditions remains un-investigated [3]. In addition, almost all studies emphasize the short-term performance rather than long-term performance of conductive concrete, such as self-healing capabilities and crack resistance [2]. Also, there are limited investigations for optimizing the equilibrium between mechanical strength and electrical properties for the field applications in road pavement, airfield pavement, bridges, roofs and structural elements [1]

2. Materials and Methods

The methodology involved in the production and evaluation of Conductive concrete is represented in flowchart as given below.

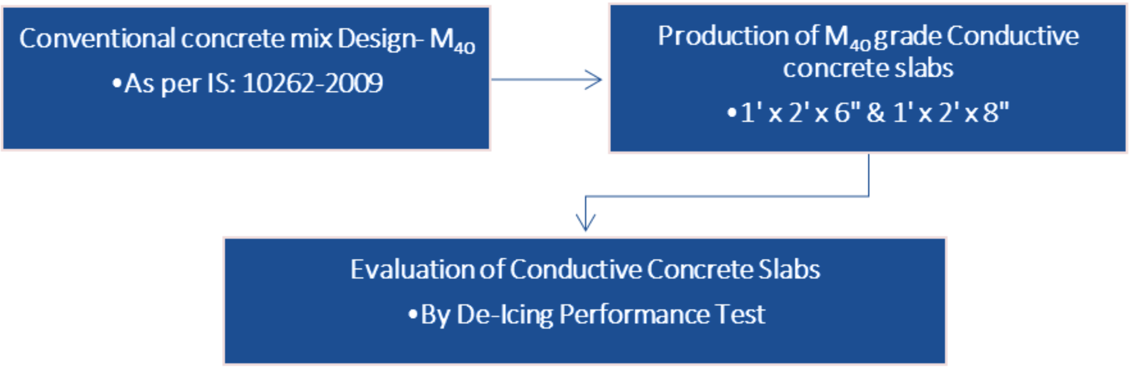


Fig. 1. Flowchart explaining methodology

2.1 Materials

The cement, fine aggregate (M sand) and coarse aggregates were used to prepare the conventional concrete. In addition to that, the carbon powder at varying percentages and constantly maintained 2% steel fiber by weight were added to the conventional concrete mix to make it as conductive concrete. Also, the reinforcement TMT steel as electrodes were inserted to the slab while casting. The materials used in this study is discussed as follows (Fig. 2.).

Fig. 2. Raw materials used

2.1.1 Cement

Cement is the binding material in cement concrete. The Ultratech OPC 43 grade cement was used as primary binder in this study. The physical tests such as Normal Consistency, Setting Time, Soundness, Compressive Strength of mortar (7, 14, 21 days) and Specific Gravity were conducted on the cement in laboratory as per guidelines mentioned in IS 4031: 1988 and results are mentioned as in the table 2.

2.1.2 Aggregates

The aggregates employed in this study were borrowed from a known local quarry in a single batch. Physical tests were conducted to know the suitability of these aggregates (Fine & Coarse aggregates) and the test results were showcased in table 3.

2.1.3 Carbon Powder

The carbon powder or carbon black is the material used as conduction filler in the cement concrete to enhance the electrical conductivity of concrete. Tiny carbon particles will increase the mobility of electrons in concrete by creating continuous electrically conductive pathways by reducing electrical resistivity. The conductive concrete used for applications like De-icing of roads, electromagnetic shielding and self-sensing concrete. It is employed as a cement-based addition in concrete mix with varying percentages by weight of cement. The percentage of carbon powder present in concrete mix will affect the electrical conductivity and mechanical properties of concrete. The carbon powder used in this study was purchased from local scientific materials and equipment dealer.

2.1.4 Steel Fiber

Steel fibers are added in electrically conductive concrete to enhance the electrical conductivity and mechanical strength. 2% steel fibers based on the weight of aggregates were added in the mix in the present study. Steel fibers enhance toughness, ductility and crack resistance of concrete and also create a continuous conductive network. These fibers have a high aspect ratio, which makes them to disperse well in the concrete matrix and providing efficient transfer of electrons. So that, the steel fibers can be used in the concrete which have the de-icing mechanism. The steel fiber material used in this study were brought from online purchase platform.

2.2 Mix Design for Conventional Concrete of M40 Grade and Conductive Concrete

The cement used for the concrete mix is OPC 43 grade, specific gravity of cement is 3.14, the coarse aggregate average specific gravity is 2.65 and of fine aggregate (M-sand) is 2.68, belongs to zone-II as per IS:383-1970(RA 2016). Super plasticizer used is FOSROC SB430 and its specific gravity is 1.145. The mix design for conventional concrete is done as IS: a 10262-2009.The mix proportion by weight in kg per m^3 is as given in table 1 below[29].

Table 1. Mix Design for Conventional Concrete (IS:10262-2009)

Cement		M-Sand		Coarse Aggregate		Water		Admixture
395 kg		724 kg		1168 kg		158.1		3.95
1	:	1.833	:	2.957	:	0.4	:	1%

The conventional concrete is made conductive concrete by adding electrically conductive materials such as steel fibers 2% by weight of aggregate and carbon powder of 8%, 10%, and 12% by weight of cement into the concrete. This makes the concrete to achieve uninterrupted 'electrical percolation' through the specimen. The flow of electrons through the composite constituents in the concrete increases the conductivity. But due to electrical resistivity of concrete, heat is gradually generated and de-icing process starts.

The mix design of electrically conductive concrete was done same as conventional concrete by following the specified IS codes. But the conductive materials like steel fibers, carbon powder and reinforcement steel as electrode were added in extra make the conventional concrete as electrically conductive. The addition of these materials to the mix has affected the strength properties in very small amount, but achieved the target strength.

2.3 Production of Conventional and Conductive Concrete

The conventional concrete is produced by mixing the dry materials as per the proportions provided in the mix design. Then water and admixture are added, mixed thoroughly, till a homogeneous mix is obtained. Then, cubes are casted and cured for 7days, 14days and 28 days and tested for compressive strength, as per IS: 516-1959 (RA 2008). The Production of Conventional and Conductive Concrete process is shown in fig. 3.

Conductive concrete is produced by adding steel fibers and carbon powder into the conventional M40 grade concrete. The concreting materials are mixed in dry condition thoroughly, then water and super plasticizer is added and mixing is continued in the drum mixer, until a uniform, homogeneous mix is obtained. Carbon powder and steel fibers are added at the end and mixing is continued for another two minutes. Cube specimens for 8%, 10%, and 12% of carbon powder by weight of cement are prepared. Steel fibers are maintained constant at 2% by weight of aggregate. For each percentage of carbon 9 cubes were casted and tested for 7,14 and 28 days.

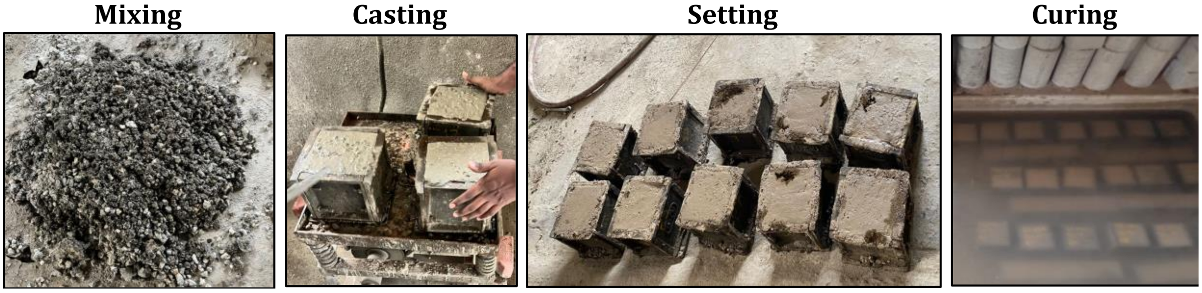


Fig. 3. Production of conventional and conductive concrete

2.4 Casting of Conductive Concrete Slabs

Conductive concrete slabs for 8%, 10% and 12% carbon powder are casted for 6inch and 8inch thickness. The size of the slab is 1feet width and 2feet length. The percentage of steel in the conductive concrete is maintained constant, as 2% by weight of total aggregate mix. The conductive concrete produced is placed in the moulds, assembled for this purpose, in three layers; each layer is vibrated for 2 minutes on the vibration table. From the top 1/3rd height 2 rods of 10mm diameter Fe-415 TMT rods are inserted from the outside of the mould as electrodes at 6inch spacing between them and 3rd layer concrete is poured and vibrated. For each percentage, 2 slabs of 6inch and 8inch thick were prepared. The total numbers of slabs are 6 numbers. These slabs are cured for 28 days by immersing the slabs in water. The process of Casting Conductive Concrete Slabs is sown in Fig. 4.

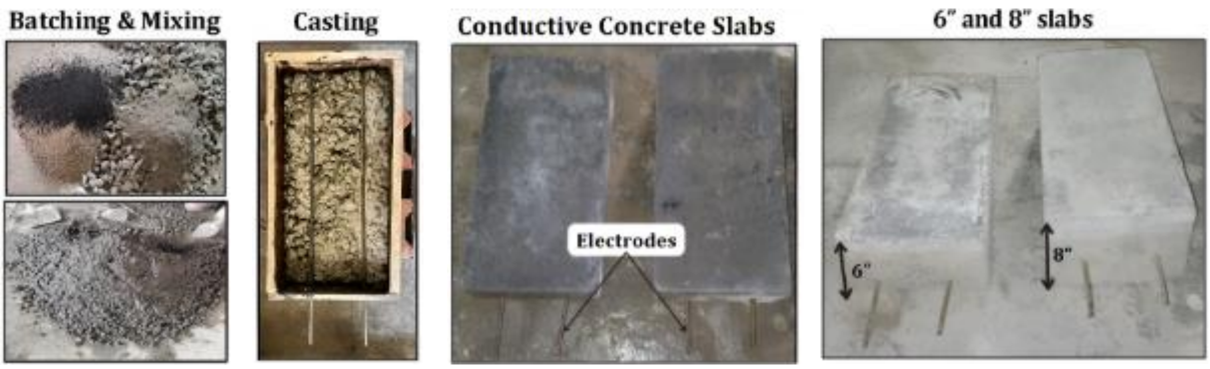


Fig. 4. Casting of conductive concrete slabs

2.5 Testing of Conductive Concrete Slabs for De-Icing Performance

After curing the slabs for 28days, are taken out and kept for surface drying in air. Then the electrodes are connected to 220v AC (Alternative Current), through auto-transformers and isolation transformers. The line diagram of electric setup of various devices is as shown in the Fig. 5.

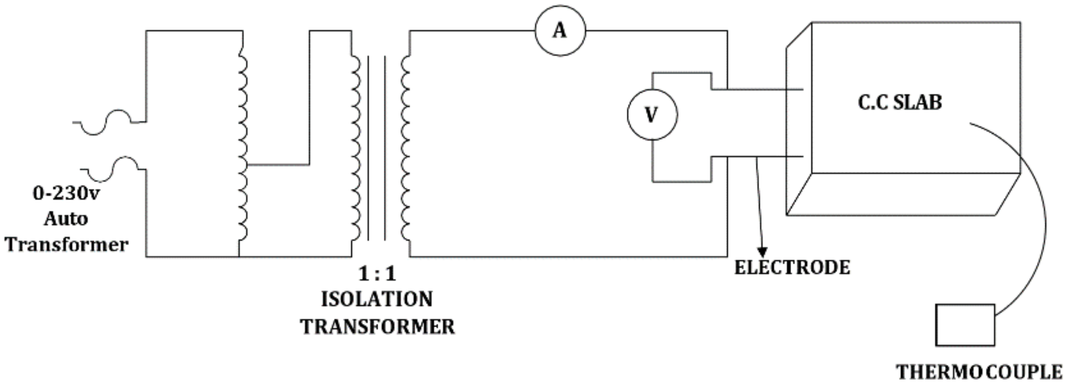


Fig. 5. Line diagram of electrical setup for conductive concrete

2.5.1 Terminology of Electric Setup

- Auto-transformer: It has a single winding on laminated core, here a winding part acts as common to both sides (primary and secondary). In loading condition, a part of current is obtained directly from supply and remaining by transformer action. This works as a voltage regulator.
- Isolation Transformer: A transformer, which will transfer the current from source to some device, by isolating that device from the source of power, for safety purpose to protect against electric shock.
- Ammeter: It is the current measuring instrument in the circuit, in amperes.
- Thermocouple: It is a sensor used to measure temperature.
- For measuring current, voltage and temperature in this study Multimeters are used.

2.6 Experimentation

2.6.1. Slump Test

The slump test was conducted on conventional and electrically conductive concrete to check the workability as per the guidelines of IS 1199 (Part 2): 2021 by slump cone method (Fig. 6). Workability of concrete in terms of Slump value is measured for both the concrete and is shown in the Table 4.

Fig. 6. Slump test

Fig. 7. Compressive strength test

2.6.2. Compressive Strength

The compression test was conducted on conventional and electrically conductive concrete to check the strength as per the guidelines of IS 516 (Part-1) 2021. The cube specimens were subjected to compression loading under compressive testing machine of frame capacity 2000kN (Fig. 7). The compressive strength of cube specimens was calculated by considering the peak load sustained by specimens and surface area of cube specimens. The results of compressive strength test are tabulated in the Table 5.

2.7 Testing for De-icing Performance:

The electrodes of the slab specimen are connected to the power source via auto-transformer & isolation transformer. To measure the current. Voltage and temperature multimeters are connected as shown in the circuit diagram. Current and voltage is measured at every 2°C increases in temperature for all the 6 conductive concrete slabs and the same is tabulated in the Table 6, 7 and 8. The Electrical test setup of conductive concrete and De-Icing process on conductive concrete is shown in Fig. 8.

Fig. 8. Electrical test setup of conductive concrete and De-Icing process on conductive concrete

3. Results and Discussions

3.1 Materials Testing

3.1.1 Tests on Cement

The laboratory test results of cement sample are satisfying the requirements of specifications mentioned in the IS Codes.

Table 2. Physical Test Results of UltraTech OPC 43 Grade Cement

List of Tests	Results	Permissible Limits	IS Code & Part
Normal Consistency (%)	30	-	IS 4031 (Part 4)
Initial Setting Time (minutes)	115	≥ 30	IS 4031 (Part 5)
Final Setting Time (minutes)	295	≤ 600	IS 4031 (Part 5)
Soundness (Le-Chatelier Expansion) (mm)	1.0	≤ 10	IS 4031 (Part 3)
Compressive Strength (MPa) – 3 Days	24.6	≥ 23	IS 4031 (Part 6)
Compressive Strength (MPa) – 7 Days	35.9	≥ 33	IS 4031 (Part 6)
Compressive Strength (MPa) – 28 Days	44.5	≥ 43	IS 4031 (Part 6)
Specific Gravity	3.14	3.10 - 3.15	IS 4031 (Part 11)

3.1.2 Tests on Aggregate

The physical test results of aggregate samples are satisfying the requirements of specifications mentioned in the IS Codes.

Table 3. Physical Test Results of Aggregates

List of Tests	Result	Permissible Limit	IS Code & Part
Fine Aggregates			
Fineness Modulus	2.60	2.2 - 2.9	IS 383:2016
Specific Gravity	2.68	2.5 - 2.9	IS 2386 (Part 3)
Water Absorption (%)	1.50	< 2.0%	IS 2386 (Part 3)
Coarse Aggregates			
Specific Gravity	2.65	2.5 - 2.9	IS 2386 (Part 3)
Aggregate Impact Value (%)	22%	< 30%	IS 2386 (Part 4)
Crushing Value (%)	26%	< 30%	IS 2386 (Part 4)
Water Absorption (%)	1.00	< 2.0%	IS 2386 (Part 3)

3.2 Slump Test on Fresh Concrete

Values of slump test in Table 4 indicate that, the workability decreased progressively with increase in the percentage of carbon powder in M_{40} grade concrete. The plain mix of concrete possessed the maximum value of 72mm slump which indicates good workability. However, on increasing the percentage of carbon powder, the slump values dropped to 68 mm, 62 mm, and 54 mm for 8% carbon powder, 10% carbon powder and 12% carbon powder respectively. This is because, the high surface area and fine particle size of carbon powder will increase the water requirement which was resulted in a reduction in amount of water in the mix.

Table 4. Slump Values of Different Concrete Mixes of M40 Grade

Sl. No.	Type of mix	Slump (mm)
1.	Conventional Concrete	72
2.	Concrete with 8% carbon powder	68
3.	Concrete with 10% carbon powder	62
4.	Concrete with 12% carbon powder	54

3.3 Compression Strength on Hardened Concrete

The strength values in Table 5 indicate a decreasing strength gradually with an increase of the carbon powder content in the concrete mix. The normal concrete mix achieved highest strength of 46.8 MPa at 28-day. Whereas 8%, 10% and 12% carbon powder mixes had slightly lower strengths of 44.1 MPa, 42.8 MPa, and 41.1 MPa respectively.

Table 5. Compressive Strength of Different Concrete Mixes of M40 Grade At Different Curing Periods

Sl. No.	Type of mix	7 Days Strength (MPa)	14 Days Strength (MPa)	28 Days Strength (MPa)
1	Conventional Concrete	29.5	38.6	46.8
2	Concrete with 8% carbon powder	28.2	36.8	44.1
3	Concrete with 10% carbon powder	27.3	34.2	42.8
4	Concrete with 12% carbon powder	25.9	32.7	41.1

The trends are same at 7 and 14 days showing that higher carbon powder content decreases the strength development. This is due to higher voids and lower cement hydration, as carbon powder may interfere with the efficiency of binding. The strength values, however, are within acceptable limits, and carbon powder is a good additive for conductive concrete application.

3.4 De-icing Performance Test

The relationship between the temperature and applied voltage, for different thickness of slabs with varying carbon powder is studied. Voltage is varied by using the regulator in the Autotransformer. As voltage is increased temperature go on increases. Voltage increase is limited to 230V only. For the observed value of temperature, current and voltage is noted. The power consumed can be obtained by taking the product of current and voltage. Current and voltage is measured at every 2°C increases in temperature for all the 6 conductive concrete slabs and the same is tabulated in the Table 6, 7 & 8 and the variation of temperature with respect to carbon powder percentage and voltage were graphically represented in the fig. 9 & 10.

Table 6. Temperature Variation in Conductive Concrete Slabs of 8% Carbon Powder for 6” and 8” Thickness

6 Inch Thickness Slab				8 Inch Thickness Slab			
Sl. No.	Voltage(V)	Current (Amperes)	Temp. (°C)	Sl. No.	Voltage(V)	Current (Amperes)	Temp.(°C)
1.	200	1.70	34	1.	204	1.72	34
2.	208	1.76	36	2.	212	1.79	36
3.	212	2.10	38	3.	216	2.20	39
4.	220	2.20	44	4.	220	2.34	45
5.	228	2.40	52	5.	230	2.46	53

Table 7. Temperature Variation in Conductive Concrete Slabs of 10% Carbon Powder for 6” and 8” Thickness

6 Inch Thickness Slab				8 Inch Thickness Slab			
Sl. No.	Voltage (V)	Current (Amperes)	Temp.(°C)	Sl. No.	Voltage(V)	Current (Amperes)	Temp. (°C)
1.	180	1.58	34	1.	182	1.59	34
2.	190	1.65	36	2.	193	1.63	36
3.	205	2.72	38	3.	208	2.70	38
4.	220	2.21	44	4.	222	2.24	45
5.	225	2.42	52	5.	225	2.44	54
6.	230	2.48	58	6.	230	2.50	58

Table 8. Temperature Variation In Conductive Concrete Slabs of 12% Carbon Powder For 6” and 8” Thickness

6 Inch Thickness Slab				8 Inch Thickness Slab			
Sl. No.	Voltage(V)	Current (Amperes)	Temp.(°C)	Sl. No.	Voltage(V)	Current (Amperes)	Temp.(°C)
1.	162	1.42	36	1.	163	1.41	36
2.	170	1.48	38	2.	172	1.46	38
3.	178	1.60	42	3.	180	1.60	42
4.	200	1.70	52	4.	202	1.72	52
5.	210	2.10	58	5.	210	2.12	58
6.	218	2.24	62	6.	218	2.25	62
7.	225	2.41	68	7.	225	2.42	68
8.	230	2.51	73	8.	230	2.54	76

The result of the de-icing performance test shows a direct correlation between applied voltage and temperature rise in conductive concrete slabs. As more carbon powder is added, the slabs conduct electricity more efficiently, giving a greater rise in temperature at lower voltages. The 6-inch and 8-inch slabs with 12% carbon powder gave the best results, with high temperatures of 73°C and 76°C, respectively, at 230V. To compare, the maximum temperatures of slabs with 10% and 8% carbon powder were lower, meaning more carbon makes them heat better. The thicker slabs use a greater current, which holds heat better. The results show that carbon powder greatly increases the self-heating ability of concrete, which can be very beneficial for de-icing in cold climates.

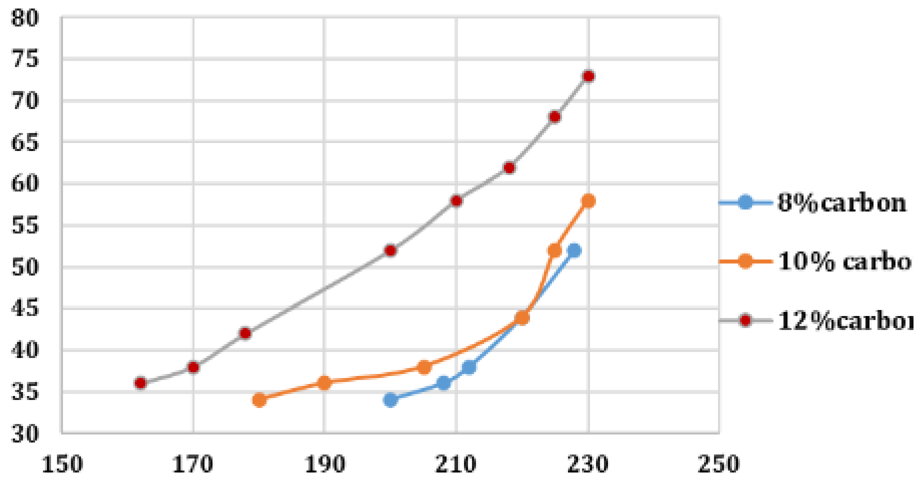


Fig. 9. Voltage v/s Temperature at 6-inch slab

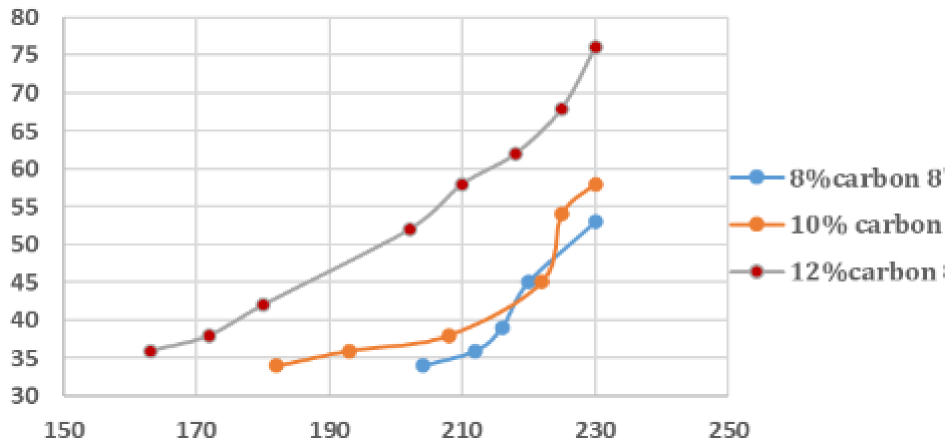


Fig.10. Voltage v/s Temperature at 8-inch slab

4. Conclusions

This study mainly concentrated on the development of electrically conductive concrete by adding carbon powder and steel fibre as conductive materials to the mix and evaluation of the same. Different trial concrete mixes were prepared and subjected to testing for evaluating workability, mechanical performance and thermal response under applied voltage. The aim was to investigate the feasibility of conductive concrete as a pavement concrete for de-icing applications when exposed to extreme cold conditions. The laboratory experimental results illustrated the effect of carbon content on workability, strength and heat generation. Thus, helping in optimizing the proper mix design for functional and structural performance.

Based on the studies, the following conclusions were made.

- A conventional concrete can be utilized as conductive concrete with the addition of commonly easily available conductive materials.
- The average strength of conventional concrete achieved at the end of 28days of curing, is nearest to the mean target strength (mean target strength is 48.5 MPa).
- The workability of concrete mix (slump value) decreases with increase in carbon powder.

- From Table-3, it is evident that compressive strength decreases with increase in carbon powder. The studies limited to 12% carbon content because any further addition reduces the strength below 40 MPa, which is normally does not recommend for highway pavements.
- An ordinary TMT bars can be used as effective electrodes.
- Table-4 to 6 shows that as applied voltage increases, temperature increases. It has been evident from the present study, that thickness of the conductive concrete slabs has little or almost nil effect on thermal property of concrete.
- This study confirms that de-icing processes is very much effective in conductive concrete, which may avoid manual clearing of ice or usage of chemicals.

4.1 Recommendations

Conductive concrete with 12% carbon powder is recommended due to its heat generation efficiency and superior electrical conductivity at lower voltages for effective de-icing applications. Increase in carbon content increases heating performance which will makes it ideal for cold regions where rapid snow and ice removal is required. The optimum slab thickness should be selected based on heating requirements and energy efficiency.

4.2 Scope for Further Work

Conductive concrete may be produced using different conductive materials for other grades of concrete. Effectiveness of electrode may be ascertained with different materials.

Acknowledgement

The authors would like to express their gratitude to all those who contributed to the completion of this research. Special thanks to Dr. L Sanjeev Kumar, HOD, EEE department for their support in setting up of electrical circuit.

References

[1] Sassani A, Arabzadeh A, Ceylan H, Kim S, Sadati S, Gopalakrishnan K, et al. Carbon fiber-based electrically conductive concrete for salt-free deicing of pavements. J Clean Prod. 2018;203:799-809. https://doi.org/10.1016/j.jclepro.2018.08.315

[2] Ernie H, Adam O, Panneer S, Mark K. Developing Anti-Icing Airfield Runways Using Conductive Concrete with Renewable Energy. J Cold Reg Eng. 2014;28(2):04014001. https://doi.org/10.1061/(ASCE)CR.1943-5495.0000064

[3] Ji X, Ge Y, Li M, Wang L, Liu S. Preparation of carbon fiber conductive concrete and study on its mechanical and heating properties. J Mater Res Technol. 2023;27:3029-40. https://doi.org/10.1016/j.jmrt.2023.10.118

[4] Chavan AD, Rattan VK, Patil YS. Improving early strength and durability of eco-friendly mortars: Investigating the influence of limestone filler fineness and blast furnace slag combination. Res Eng Struct Mater. 2024. https://doi.org/10.17515/resm2024.232st0404rs

[5] EL-Afandi M, Yehia S, Landolsi T, Qaddoumi N, Elchalakani M. Self-Consolidated Concrete-to-Conductive Concrete Interface: Assessment of Bond Strength and Mechanical Properties. Fibers. 2023;11(12). https://doi.org/10.3390/fib11120106

[6] Benaddi H, Rebai B, Messas T, Salhi M. Evaluation of self-compacting concrete for concrete repair applications. Res Eng Struct Mater. 2024. https://doi.org/10.17515/resm2024.255st0423rs

[7] Anis M, Abdel-Raheem M. A Review of Electrically Conductive Cement Concrete Pavement for Sustainable Snow-Removal and Deicing: Road Safety in Cold Regions. Transp Res Rec. 2024. https://doi.org/10.1177/03611981231225210

[8] Maleki P, Iranpour B, Shafabakhsh G. Investigation of de-icing of roads with conductive concrete pavement containing carbon fibre-reinforced polymer (CFRP). Int J Pavement Eng. 2019;20:682-90. https://doi.org/10.1080/10298436.2017.1326235

[9] Ren Z, Peng Y, Chen X, Zeng H, Zeng X, Kontoleon K. Research on Electrical Conductivity and Mechanical Properties of Ecological Concrete Prepared from Mine Solid Waste. Adv Civ Eng. 2023;2023. https://doi.org/10.1155/2023/6299237

[10] del Moral B, Ureña A, Sánchez-Rodríguez D, Muñoz M, Nieto JE. Temperature and humidity influence on the strain sensing performance of hybrid carbon nanotubes and graphite cement composites. Constr Build Mater. 2021;284:122786. https://doi.org/10.1016/j.conbuildmat.2021.122786

[11] Li C, Ge H, Sun D, Zhou X. Novel conductive wearing course using a graphite, carbon fiber, and epoxy resin mixture for active de-icing of asphalt concrete pavement. Mater Struct. 2021;54(1):48. https://doi.org/10.1617/s11527-021-01628-7
[12] Bakbolat B, Abduzhanov A, Tuleubekov A, Mukanova A, Kuterbekov K, Ibragimov R, et al. Effectiveness of Bio-Waste-Derived Carbon Doping on De-Icing Performance of an Electrically Resistant Concrete. Coatings. 2022;12(11). https://doi.org/10.3390/coatings12111629
[13] Wang X, Wu Y, Zhu P, Ning T. Snow melting performance of graphene composite conductive concrete in severe cold environment. Materials (Basel). 2021;14(21). https://doi.org/10.3390/ma14216715
[14] Bellatrache Y, Ziyani L, Dony A, Taki M, Haddadi S. Effects of the addition of date palm fibers on the physical, rheological and thermal properties of bitumen. Constr Build Mater. 2020;239:117808. https://doi.org/10.1016/j.conbuildmat.2019.117808
[15] Pereira I, Miranda T, Pereira E. Electrically conductive cementitious composites for marine applications. J Sustain Cem Based Mater. 2024;13(6):899-917. https://doi.org/10.1080/21650373.2024.2338529
[16] Farcas C, Bistrian DA, Dumitru C, Ciuca I, Utu D, Utu I, et al. Heating and de-icing function in conductive concrete and cement paste with the hybrid addition of carbon nanotubes and graphite products. Smart Mater Struct. 2021;30(4):045002. https://doi.org/10.1088/1361-665X/abe032
[17] Wang Y, Zhao W, Tan L, Li Y, Qin L, Li S. Review of Polymer-Based Composites for Electromagnetic Shielding Application. Molecules. 2023;28(15). https://doi.org/10.3390/molecules28155628
[18] Galao O, Bañón L, Baeza FJ, Carmona J, Garcés P. Highly conductive carbon fiber reinforced concrete for icing prevention and curing. Materials (Basel). 2016;9(4). https://doi.org/10.3390/ma9040281
[19] Venkatraman K, Tamizharasan V. Electrically Conductive Concrete. Int J Innov Res Sci Eng Technol. 2007;3297.
[20] Farcas C, Bistrian DA, Dumitru C, Ciuca I, Utu D, Utu I, et al. Heating and de-icing function in conductive concrete and cement paste with the hybrid addition of carbon nanotubes and graphite products. Smart Mater Struct. 2021;30(4):045002. https://doi.org/10.1088/1361-665X/abe032
[21] Lu D, Leng Z, Lu G, Wang D, Huo Y. A critical review of carbon materials engineered electrically conductive cement concrete and its potential applications. Int J Pavement Eng. 2023. https://doi.org/10.1080/19475411.2023.2199703
[22] Li M, Zhong J, Li G, Zhang Q, Cen F, Gao P. Study on the Performance of Polymer-Modified Conductive Cement-Based Materials. Buildings. 2023;13(12). https://doi.org/10.3390/buildings13122961
[23] Wu T, Huang R, Chi M, Weng T. A study on electrical and thermal properties of conductive concrete. Comput Concr. 2013;12(3):337-49. https://doi.org/10.12989/cac.2013.12.3.337
[24] Savytskyi M, Sukhyy K, Savytskyi O, Babenko M, Shevchenko T. Carbon materials for electrically conductive concrete. In: E3S Web Conf. EDP Sciences; 2024. https://doi.org/10.1051/e3sconf/202453401019
[25] Tian X, Hu H. Test and Study on Electrical Property of Conductive Concrete. Procedia Earth Planet Sci. 2012;5:83-7. https://doi.org/10.1016/j.proeps.2012.01.014
[26] Chung DDL. Electrically conductive cement-based materials. Adv Cem Res. 2004;16(4):167-76. https://doi.org/10.1680/adcr.2004.16.4.167
[27] Tuan C. Implementation of Conductive Concrete for Deicing (Roca Bridge). Aug. 2008.
[28] Dehghanpour H, Yılmaz K. Heat Behavior of Electrically Conductive Concretes with and without Rebar Reinforcement. Mater Sci. 2020;26:471-6. https://doi.org/10.5755/j01.ms.26.4.23053
[29] Bureau of Indian Standards. IS 10262 (2009): Guidelines for concrete mix design proportioning.