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AUSTRALIAN SECURITIES EXCHANGE ANNOUNCEMENT

22 July 2026

Positive Indian Government EdenCrete® Trials

CRRI Concrete Trials Show EdenCrete®Pz7 Significantly Improves:

- **Strength**
- **Abrasion Resistance and**
- **Shrinkage Performance**

compared to control mixes.

The EdenCrete®Pz7 trials in Indian concrete mixes trials conducted by the Central Road Research Institute (CRRI), an Indian Government agency, in the CRRI laboratory in Delhi in May 2026 at the request of Eden (see ASX announcement of preliminary results of 22 June 2026), have produced highly encouraging results as outlined in the attached final study report ("the Report") as received on 21 July 2026.

HIGHLIGHTS

The EdenCrete®Pz7 enriched concrete mixes delivered the following comparative performances against the control concrete mixes without EdenCrete®Pz7 as recorded in the Report:

- **Significantly increased abrasion resistance by up to 28% (i.e. reducing abrasion loss),**
- **Significantly reduced the drying-shrinkage of concrete by up to 25%, with the 25% maximum reduction in the concrete mixes containing fly ash,**
- **Reduced by up to 17% the drying-shrinkage of concrete mixes with no fly ash in the mixes but containing 50 kg/m³ additional cement content,**
- **Increased compressive strength by up to 19%;**
- **Increased flexural strength by up to 14%;**
- **Improved slightly the workability of paving-grade concrete mixes; and**
- **Had no significant effect on fresh or dry density of paving-grade concrete mixes.**

DETAILS

The EdenCrete®Pz7 enhanced concrete mixes, with between 0.25 - 0.3 litres of EdenCrete®Pz7 per cubic metre of concrete, were trialled by CRRI at the request of Eden, against the same concrete mixes but without the added EdenCrete®Pz7 ("the Reference") in an extensive series of trials.

Two concrete mixes were trialled:

- **The first mix trialled was a 40 MPa strength concrete mix that is used for new highways. Presently India is endeavouring to build 4 kilometres of new highway per day; and**
- **The second mix trialled was a 60 MPa strength concrete mix that is used for "white topping", a high strength, thin layer of concrete that is used as an overlay to repair worn concrete pavement. Since 2014 India is reported to have built over 50,000 kilometres of new concrete highways, much of which is now in need of repairs.**

The EdenCrete® enhanced concrete delivered impressive performance increases in most of the trials, and with the remainder of the trials, the EdenCrete® enhanced concrete performed at least as well as the References.

CRRI Final Report from EdenCrete® Trials

The conclusion in the Report (see pages 22-23) summarised the results of the trials as follows:

" CONCLUSIONS

The following conclusions may be drawn from the present study:

1. *The incorporation of carbon nanotubes (CNT) resulted in a slight improvement in the workability of paving-grade concrete mixes.*

2. *The inclusion of CNT had no significant effect on the fresh or dry density of the paving-grade concrete mixes.*

3. *The incorporation of CNT significantly enhanced the compressive strength of concrete, with improvements of up to 19% compared to the corresponding control mixes.*

4. The flexural strength of concrete was improved by up to 14% through the incorporation of CNT. The maximum increase was observed in the fly ash-

containing mixes, while the minimum improvement, approximately 11%, was recorded in the mixes without fly ash but containing 50 kg/m³ higher cement content. Page | 23 CSIR-Central Road Research Institute (CRRI) New Delhi

5. The influence of CNT on the splitting tensile strength of concrete was relatively limited, with improvements of up to approximately 5% compared to the corresponding control mixes.

6. CNT incorporation significantly improved the abrasion resistance of concrete, reducing abrasion loss by up to 28% compared to the corresponding control mixes. The maximum enhancement was observed in the fly ash-containing concrete mixes, whereas the minimum reduction in abrasion loss, approximately 15%, was recorded in the mixes without fly ash.

7. The incorporation of CNT significantly reduced the drying-shrinkage of concrete, with reduction of up to 25% compared to the corresponding control mixes. The maximum reduction in drying-shrinkage was observed in the fly ash-containing mixes, whereas the minimum reduction, approximately 17%, was recorded in the mixes without fly ash but containing 50 kg/m³ higher cement content.

8. The results indicate that the presence of fly ash plays a crucial role in maximizing the beneficial effects of CNT incorporation in concrete.

9. The findings further demonstrate that the synergistic interaction between fly ash and CNT is instrumental in achieving the greatest improvements in concrete performance.

10. The study highlights the potential of CNT-based admixtures to reduce cement consumption while maintaining the required strength and durability characteristics. This offers a promising approach for developing cost-effective and environmentally sustainable concrete mixtures for pavement applications."

Follow-up on CRRI Report

Eden India intends to explore with CRRI ways to accelerate appropriate field trials of EdenCrete® enriched concrete for new highways and white topping highway repairs.
CRRI is highly respected across all Indian Federal and State Governments, and the Report could assist Eden to break into the Indian infrastructure market including highways, bridges, airports, ports, data centres, military and defence facilities**.**

CRRI – Background and Roles

Central Road Research Institute (CRRI)[1]. a premier national laboratory established in 1952, and a constituent of Council of Scientific and Industrial Research (**CSIR**), is engaged in carrying out research and development projects. These projects include:

- design, construction and maintenance of roads and runways,
- traffic and transportation planning of mega and medium cities,
- management of roads in different terrains,
- improvement of marginal materials,
- utilization of industrial waste in road construction,
- landslide control,
- ground improvements environmental pollution,
- road traffic safety and analysis and design,
- wind, fatigue, corrosion studies, performance monitoring/evaluation, service life assessment and
- rehabilitation of highway and railway bridges.

1. **https://crridom.gov.in/en**

CRRI also provides technical and consultancy services to the Indian Government and various user organizations in India and abroad, and is dedicated to pioneering sustainable, localised concrete technologies and materials for India’s highway and runway infrastructure.

CRRI Premises in Delhi, India

CRRI also focuses heavily on adapting concrete engineering for India's extreme climatic conditions and heavy traffic. Primary research areas include:

- **Rigid Pavements & Overlays:** The institute heavily promotes Roller compacted concrete for pavements and Ultra-Thin White Topping (UTWT) using high-performance fibre reinforcement to extend the lifespan of existing bituminous roads;

- **Industrial Byproduct Utilisation:** CRRI studies the use of fly ash and Ground Granulated Blast Furnace Slag and steel slag as partial cement replacements to build robust, climate-resilient roads; and
- **Sustainable & Lightweight Mixes:** In collaboration with CSIR-CBRI, the institute conducts research on advanced, sustainable lightweight concrete and uses advanced concrete admixtures (like EdenCrete®) to enhance durability.

Indian Concrete Market- Major Growth Sectors

As reported in Eden's ASX Announcement on 22 June 2026, a rapid growth in concrete consumption is taking place driven by various factors:

- **Record-breaking government capital expenditure and massive urbanization**, with India now being the second largest construction growth market in the world, closely behind China, and having passed the USA.
- **Significant increase in construction of new high-rise residential apartments** across India (and in Delhi in particular) requiring very high strength concrete.
- **The Indian government has allocated to infrastructure a record** ₹12.20 lakh crore (12.2 trillion INR or approximately USD 135 billion) spending for FY26–27.
- **Since 2014 India has built approximately 50,000 kms of new concrete highways** (out of a total of around 100,000 kms of highways including asphalt) and continues **building approximately 4 kms of new concrete highways per day**.
- **Recent trials of EdenCrete®Pz7 conducted with two Indian ready-mix concrete companies and with private major Indian property developers, have produced encouraging results** like those detailed in the CRRI Report, showing:
  - Increased strength of High Strength Concrete, 50 MPa and above, immediately convertible to significant cost-savings for these mixes;
  - The strength buffer, enables replacement of expensive Ordinary Portland Cement ("**OPC**") and micro silica mix content with much cheaper supplementary cementitious materials (SCMs) such as fly ash or slag;
  - Improved other performance characteristics of the concrete; and
- **Reducing the CO_2 footprint through the reduced use of OPC** and/or increased replaced with far lower CO_2 intense SCMs (see Eden's announcement (EDE:ASX) of 22 June 2026).

CONCLUSION

EdenCrete®Pz7 enhanced concrete has clearly outperformed the standard concrete mixes in the various Indian trials that have recently been conducted, using higher levels of fly-ash in the concrete with low dosages of EdenCrete®Pz7, resulting in stronger, cheaper concrete with lower CO_2 footprints, offering attractive alternatives to the current, higher priced materials presently being used.

Considering the Indian concrete market, coupled with wide range of benefits that the long-proven EdenCrete® admixtures deliver, being:

- ***the size and rapid growth rate of the Indian concrete market;***
- ***the comprehensively trialled, validated, and documented performance of the EdenCrete® products in Indian concrete mixes as confirmed in the CRRI Report;***
- ***the consistent cost benefits delivered to the concrete producers;***
- ***the frequent reduction in CO_2 footprints; and***
- ***the fact that the EdenCrete® admixtures are, so far as Eden is aware, the only carbon nanotube-enhanced concrete admixtures that are commercially produced, extensively trialled and commercially used and proven over more than ten years in numerous countries***

Eden is confident that, with the publication and circulation of the CRRI Report, its EdenCrete® admixtures, which have experienced significant market growth in North and South America over the past three years, could soon see similar growth in the Indian concrete market, potentially resulting in India becoming Eden's largest market for its EdenCrete® products over the next few years.

Gregory H. Solomon
Executive Chairman

This announcement was authorised by the above signatory.
For further information please contact Greg Solomon on +61 8 9282 5889.

Forward Looking Statements
Statements contained in this release, particularly those regarding possible or assumed future performance, revenue, costs, dividends, production levels or rates, prices or potential growth of the Company are, or may be, forward looking statements. Such statements relate to future events and expectations and as such, involve known and unknown risks and uncertainties. Actual results and developments may differ materially from those expressed or implied by these forward-looking statements depending on a variety of factors. The past performance of the Company is no guarantee of future performance.

None of the Company's directors, officers, employees, agents or contractors makes any representation or warranty (either express or implied) as to the accuracy or likelihood of fulfilment of any forward looking statement, or any events or results expressed or implied in any forward looking statement, except to the extent required by law. You are cautioned not to place undue reliance on any forward looking statement. Any forward looking statements in this announcement reflect views held only as at the date of this announcement.

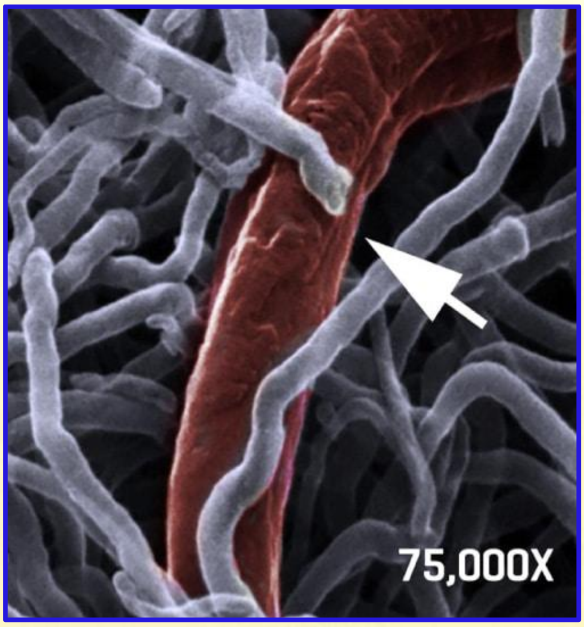
बुनियादी ढांचे के निर्माण के लिए सीमेंट कंक्रीट में ईडनक्रीट सीएनटी मिश्रण का प्रदर्शन मूल्यांकन

Performance Evaluation of EdenCrete CNT Admixture in Cement Concrete for Infrastructure Construction

Sponsored by

Eden Innovations India Private Limited

Final Report



June 2026

Rigid Pavement Division

दृढ़ कुट्टिम प्रभाग

सी एस आई आर - केंद्रीय सड़क अनुसंधान संस्थान, नई दिल्ली-110025

CSIR - CENTRAL ROAD RESEARCH INSTITUTE
NEW DELHI-110025

बुनियादी ढांचे के निर्माण के लिए सीमेंट कंक्रीट में ईडनक्रीट सीएनटी मिश्रण का प्रदर्शन मूल्यांकन

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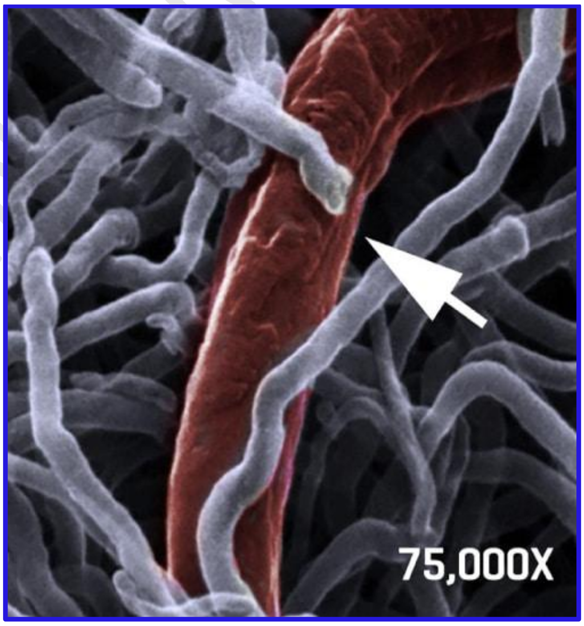

June 2026

Rigid Pavement Division

दृढ़ कुट्टिम प्रभाग

सी एस आई आर - केंद्रीय सड़क अनुसंधान संस्थान, नई दिल्ली-110025

CSIR - CENTRAL ROAD RESEARCH INSTITUTE
NEW DELHI-110025

(Report No. QSP/CRRI/RPD/CNP-3010)

अंतिम रिपोर्ट

बुनियादी ढांचे के निर्माण के लिए सीमेंट कंक्रीट में ईडनक्रीट सीएनटी मिश्रण का प्रदर्शन मूल्यांकन

Final Report

Performance Evaluation of EdenCrete CNT Admixture in Cement Concrete for Infrastructure Construction

Sponsored by

EDEN INNOVATIONS INDIA PRIVATE LIMITED

Dr. Ch. Ravi Sekhar

Director

Mrs. Lalita Jangpangi

HOD, Rigid Pavement Division

STUDY TEAM

Dr. Pankaj Goel,	**Senior Technical Officer (3)**	**Project Leader**
Dr. Rakesh Kumar	Chief Scientist (Retd. RPD)	Team Member
Sh. Surendra Singh	Technical Assistant	Team Member
Sh. Ashwani Kumar	Technician	Team Member

DISCLAIMER

All the data and technical information furnished in this report are material-specific and based on the investigation conducted at the CSIR-CRRI laboratory on materials provided by officials of Eden Innovations India Private Limited. The responsibility of CSIR-CRRI is limited to the technical and scientific matters contained in the report only. Proper quality control at the plant and construction site, as well as the quality of materials to be used for concrete manufacturing, shall be the responsibility of the client.

Any use of the data provided in the report without consulting CSIR-CRRI by any other agency or person other than the client is solely at their own risk and responsibility.

अस्वीकरण

इस रिपोर्ट में दिया गया सारा डेटा और तकनीकी जानकारी खास तौर पर उस मटीरियल से जुड़ी है, जिसकी जांच CSIR-CRRI लैब में 'ईडन इनोवेशन इंडिया प्राइवेट लिमिटेड' के अधिकारियों द्वारा उपलब्ध कराए गए सैंपल पर की गई थी। CSIR-CRRI की ज़िम्मेदारी सिर्फ़ रिपोर्ट में शामिल तकनीकी और वैज्ञानिक मामलों तक ही सीमित है। प्लांट और कंस्ट्रक्शन साइट पर सही क्वालिटी कंट्रोल, और कंक्रीट बनाने में इस्तेमाल होने वाले मटीरियल की क्वालिटी की ज़िम्मेदारी क्लाइंट की होगी।

अगर क्लाइंट के अलावा कोई दूसरी एजेंसी या व्यक्ति CSIR-CRRI से सलाह लिए बिना इस रिपोर्ट में दिए गए डेटा का इस्तेमाल करता है, तो ऐसा करना पूरी तरह से उनके अपने जोखिम और ज़िम्मेदारी पर होगा।

ACKNOWLEDGEMENTS

CSIR-Central Road Research Institute (CSIR-CRRI), Mathura Road, New Delhi, is grateful to Dr. Allan Godsk Larsen, Chief Scientist & Managing Director, Eden Innovations Limited and Sh. Manish H. Dixit, Director, Eden Innovations India Private Limited, S2, Kushan Apartments, Friends Colony, Ambawadi, Ahmedabad, Gujarat, for entrusting and sponsoring the project of "**Performance Evaluation of EdenCrete CNT Admixture in Cement Concrete for Infrastructure Construction**". We want to express our gratitude to Sh. Mukesh Mokha, Former Consultant, Eden Innovations India Private Limited, for his invaluable inputs, help, and support whenever required. We would also like to thank Mr. Sunil Kumar, Technical Sales Manager, MBT Construction Chemicals India Private Limited, for his support during the manufacture of concrete specimens.

We would also like to thank all those who helped generate the data needed for the laboratory investigation work for this project.

FOREWORD

QSP/RPD/ Final Report/ CNP-3010/13
17th July 2026

To,
Sh. Manish H. Dixit,
Director, Eden Innovations India Private Limited,
S2, Kushan Apartments, Friends Colony, Ambawadi, Ahmedabad, Gujarat

Sub: Submission of Final Report on "Performance Evaluation of EdenCrete CNT Admixture in Cement Concrete for Infrastructure Construction".

Sir,

With reference to the above subject, please find attached herewith a copy of "Final Report" on "**Performance Evaluation of EdenCrete CNT Admixture in Cement Concrete for Infrastructure Construction**".

Dr. Pankaj Goel

Mrs. Lalita Jangpangi,
HoD, Rigid Pavement Division

EXECUTIVE SUMMARY

Sh. Manish H. Dixit, Director, Eden Innovations India Private Limited, Ahmedabad, Gujarat, approached CSIR–Central Road Research Institute (CSIR-CRRI) to evaluate the potential benefits of incorporating the EdenCrete CNT-based admixture into cement concrete for infrastructure construction. Subsequently, a comprehensive laboratory investigation was undertaken to assess the effectiveness of the EdenCrete CNT-based admixture in cement concrete intended for rigid pavement applications. The performance of the EdenCrete CNT-based admixture for rigid pavement applications was evaluated through a comprehensive laboratory investigation using M40 and M60 paving-grade concrete mixes. The assessment included determining fresh concrete properties and key engineering and durability characteristics, namely compressive strength, splitting tensile strength, flexural strength, drying shrinkage, and abrasion resistance. The study concludes that, incorporation of carbon nanotubes (CNT, dosage: 250ml/m^3 and 300ml/m^3) resulted in a slight improvement in the workability of paving-grade concrete mixes. However, inclusion of CNT had no significant effect on the fresh or dry density of the paving-grade concrete mixes. The incorporation of CNT significantly enhanced the compressive (up to 19%) and flexural strength (up to 14%) of concrete, compared to the corresponding control mixes. The influence of CNT on the splitting tensile strength of concrete was relatively limited, compared to the corresponding control mixes. CNT incorporation significantly improved the abrasion resistance of concrete, reducing abrasion loss by up to 28% compared to the corresponding control mixes. Further, the incorporation of CNT significantly reduced the drying-shrinkage of concrete, with reduction of up to 25% compared to the corresponding control mixes. The maximum increase in strength properties and durability criteria (abrasion loss and drying shrinkage) was observed in the fly ash-containing mixes, while the minimum improvement was recorded in the mixes without fly ash but containing 50 kg /m^3 higher cement content. The results indicate that the presence of fly ash plays a crucial role in maximizing the beneficial effects of CNT incorporation in concrete. The findings further demonstrate that the synergistic interaction between fly ash and CNT is instrumental in achieving the greatest improvements in concrete performance. The study highlights the potential of CNT-based admixtures to reduce cement consumption while maintaining the required strength and durability characteristics. This offers a promising approach for developing cost-effective and environmentally sustainable concrete mixtures for pavement applications.

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1. INTRODUCTION

Sh. Manish H. Dixit, Director, Eden Innovations India Private Limited, Ahmedabad, Gujarat, approached CSIR–Central Road Research Institute (CSIR-CRRI) to evaluate the potential benefits of incorporating the EdenCrete CNT-based admixture into cement concrete for infrastructure construction, vide his letter dated 23rd April 2025. CSIR-CRRI accepted the assignment on 1st May 2025 and communicated its acceptance to the client through Letter No. CRRI/RP/Eden Innovation/1 dated 1st May 2025.

Subsequently, a comprehensive laboratory investigation was undertaken to assess the effectiveness of the EdenCrete CNT-based admixture in cement concrete intended for rigid pavement applications. The study was carried out using commonly adopted paving-grade concrete mixes of M40 and M60 strength grades. This report presents the adopted methodology, the experimental programme, and the results obtained from the investigation.

2. EXPERIMENTAL INVESTIGATION

The performance of the EdenCrete CNT-based admixture for rigid pavement applications was evaluated through a comprehensive laboratory investigation using M40 and M60 paving-grade concrete mixes. The assessment included determining fresh concrete properties and key engineering and durability characteristics, namely compressive strength, splitting tensile strength, flexural strength, drying shrinkage, and abrasion resistance.

All constituent materials, including the concrete mix designs used for the preparation of test specimens, were supplied by the client. A series of standardized laboratory tests was conducted to assess the suitability and effectiveness of the admixture for pavement concrete applications. The details of specimen preparation, test procedures adopted for evaluating the various properties of concrete, and the corresponding results obtained from the investigation are presented in the following sections.

2.1. Material Properties

The following constituent materials were utilized in the manufacture of the paving-grade concrete mixes and the preparation of test specimens for evaluating the fresh, mechanical, and durability properties of concrete:

2.1.1 Ordinary Portland Cement

Ordinary Portland Cement (OPC), 43 Grade, manufactured by Ultra-Tech and conforming to the provisions of IS 4031:1988 and IS 269:2015, was used in all concrete mixes investigated in this study. The relevant physical properties of the cement are summarized in Table 1. Figure 1 presents a typical cement mortar cube specimen after failure under compressive loading.

Table 1: Physical Properties of Ordinary Portland Cement (OPC)

<table>
<tr><td>Brand of Cement</td><td colspan="3">Ultra-tech</td></tr>
<tr><td>Type of Cement</td><td colspan="3">Ordinary Portland Cement</td></tr>
<tr><td>Grade of Cement</td><td colspan="3">43</td></tr>
<tr><td>Specific Gravity of Cement</td><td colspan="3">3.15</td></tr>
<tr><td>Normal Consistency of cement</td><td colspan="3">29 %</td></tr>
<tr><td>Initial Setting Time</td><td colspan="3">132 minutes > 30 minutes, ok Passed</td></tr>
<tr><td>Final Setting Time</td><td colspan="3">246 minutes < 600 minutes, ok Passed</td></tr>
<tr><td rowspan="4">Average Compressive strength, MPa</td><td>Age attest</td><td>Average of three Samples</td><td>Reference</td></tr>
<tr><td>3 - Day</td><td>27.5 > 23</td><td rowspan="3">IS-4031: 1988</td></tr>
<tr><td>7 - Day</td><td>35.6 > 33</td></tr>
<tr><td>28-Day</td><td>45.5 > 43</td></tr>
</table>

Fig. 1: A typical view of the Cement Mortar Cube after Test

2.1.2 Fly Ash

Class F fly ash, conforming to ASTM C618-19, was supplied by the client and evaluated in accordance with the procedures specified in IS 1727:1967 and IS 3812:2003. The client provided the test report (No. 20250521-1095 dated 21.05.2025) issued by TrueScience Research & Testing Lab Pvt. Ltd., Sector 63, Noida, Uttar Pradesh.

The physical and chemical properties of the fly ash used in the present investigation are summarized in Tables 2 and 3, respectively. As evident from Table 2, the fly ash exhibits satisfactory pozzolanic reactivity, with a compressive strength exceeding 4.5 MPa. Accordingly, it was utilized as a partial replacement for cement in the M40 and M60 paving-grade concrete mixes investigated in this study.

Table 2: Physical Properties of the Fly Ash

Sl./ Nos	Properties	Measured Value	Permissible Value as per IS 3812-2003
1	Fineness-specific surface in m^2/kg	384	>320
2	Specific Gravity	2.19	-
3	Particles Passing on 75μ Sieve, %	78	-
4	Particles Retained on 45μ Sieve, %	27.3	<34
5	Lime Reactivity, MPa	4.7	> 4.5
6	Loss of Ignition , % by mass	0.66	< 5

Table 3: Chemical Properties of the Fly Ash

Sl./ Nos	Properties	Measured Value	Permissible Value as per IS 3812-2013 and IS: 1727-1967
1	Silicon dioxide (SiO_2) % + aluminum oxide (Al_2O_3)% + Iron Oxide (Fe_2O_3), %	93.28	>70
2	Silicon dioxide (SiO_2), % by mass	54.29	>35
3	Magnesium oxide (MgO), % by mass	0.85	<5.0
4	Total Sulphur (SO_3), % by mass	0.40	<3.0
5	Available Alkalis equivalent as Sodium oxide (Na_2O), % by mass	0.68	<1.5
6	Total Chlorides, % by mass	0.014	<0.05

2.1.3 Silica Fume

Dry silica fume conforming to the requirements of ASTM C1240-2005 was used as a partial replacement for cement in the manufacture of M60 paving-grade concrete mixes. The physical properties of the silica fume (Micro Silica® 920 D), as reported by the manufacturer, are presented in Table 4. As shown in Table 4, the silica fume contains more than 85% active silica, indicating its high pozzolanic reactivity and suitability as a supplementary cementitious material. The table further shows that the percentage retained on the 45 µm sieve is less than 10%, which satisfies the requirements of ASTM C1240-2005. This low retention value reflects the extremely fine nature of silica fume particles compared with cement and fly ash and also indicates the absence of significant contaminating or coarser materials.

Table 4: Physical Properties of the Silica Fume

Property	Value
Active Silica (%)	> 85
Retained on 45µm Sieve (%)	< 10
Loss on Ignition (%)	< 6
Specific Surface Area (m^2/g)	> 15
Pozzolonic Activity Index (%)	> 105

2.1.4 Aggregates (Coarse and Fine)

2.1.4.1 Coarse Aggregate:

Crushed quartzite coarse aggregates with nominal m.s.a. (mean size aggregate) of 20mm and 10mm were used at the client's request. Otherwise, the maximum aggregate size is kept at 31.5mm for the construction of concrete pavement. The physical properties and gradation of both the aggregates are presented in Tables 5, 6 and 7, respectively.

Table 5: Physical Properties of Coarse Aggregates

Name of Test	Size of aggregate	
	20 mm	10 mm
Specific Gravity	3.0	3.0
Water Absorption (%)	0.35	0.35
Aggregate crushing value (%)	19.2	
Aggregate impact value (%)	11.3	

Table 6: Gradation of 20mm Aggregate

Sieve Size (mm)	% Passing			Average of three samples, %
	Sample 1	Sample 2	Sample 3	
26.5	100	100	100	100
19	92.34	94.68	91.4	93
9.5	2.9	1.6	1.0	1.8
4.75	0.3	0.3	0.4	0.3
0.600	0.0	0.0	0.0	0.0

Table 7: Gradation of 10mm Aggregate

Sieve Size (mm)	% Passing			Average of three samples, %
	Sample 1	Sample 2	Sample 3	
19	100	100	100	100
9.5	90.0	86.8	85.3	87.4
4.75	7.4	7.6	5.7	6.9
0.600	0.0	0.0	0.0	0.0

2.1.4.2 Fine Aggregate:

Locally available quarry sand was used as the fine aggregate in the present investigation. The material was characterized in accordance with the procedures specified in IS 2386:1963. The specific gravity, water absorption, and clay and silt contents of the sand were determined to be 2.64, 1.35%, and 1.7%, respectively. The particle size distribution (gradation) of the fine aggregate is presented in Table 8.

Table 8: Gradation of Fine Aggregate

Sieve Size (mm)	% Passing			Average of three samples, %
	Sample 1	Sample 2	Sample 3	
9.5	100	100	99.7	100
4.75	89.4	92.7	88.2	90.1
0.600	67.1	64.6	66.5	66.1
0.150	7.2	5.3	9.4	7.3
0.075	1.7	0.8	2.5	1.7

2.1.4.3 All- in –Aggregate Blending

All in aggregate blending used for the manufacturing of M40 and M60 paving-grade concrete is presented in Tables 9 & 10, respectively. It can be seen from the Tables that blending used meets the requirements of the Indian Roads Congress (IRC).

Table 9: All-in-Aggregate Combined Gradation used for M40 Paving-Grade Concrete

Sieve Size(mm)	20 mm		10 mm		Sand		Overall % passing	Specified Limits for 19 mm (IRC:44-2017)
	% passing	% used 33	% passing	% used 33	% passing	% used 34		
31.5	100	33	100	33	100	34	100.0	100
26.5	100	33	100	33	100	34	100.0	100
19	93	30.7	100	33	100	34	97.7	90-100
9.5	1.8	0.6	87.4	28.8	100	34	63.4	48-78
4.75	0.3	0.1	6.9	2.3	90.1	30.6	33.0	30-58
600	0	0.1	0	0.0	66.1	22.5	22.5	(8-35)
150	0	0	0	0	7.3	2.5	2.5	0-12
75	0	0	0	0	1.7	0.6	0.6	0-2

Table 10: All-in-Aggregate Combined Gradation used for M60 Paving-Grade Concrete

Sieve Size(mm)	20 mm		10 mm		Sand		Overall % Passing
	% passing	% used 0	% passing	% used 53.6	% passing	% used 46.4	
31.5	100	0	100	53.6	100	46.4	100.0
26.5	100	0	100	53.6	100	46.4	100.0
19	93	0	100	53.6	100	46.4	100.0
9.5	1.8	0	87.4	46.8	100	46.4	93.2
4.75	0.3	0	6.9	3.7	90.1	41.8	45.5
600	0	0	0	0	66.1	30.7	30.7
150	0	0	0	0	7.3	3.4	3.4
75	0	0	0	0	1.7	0.8	0.8

2.1.5 Superplasticiser:

Polycarboxylate ether (PCE)-based high-range water-reducing admixtures (HRWRAs), namely Master Glenium SKY 8650 and Master Glenium SKY 8866, supplied by the client, were used in the preparation of the M40 and M60 paving-grade concrete mixes, respectively. Master Glenium SKY 8650 was incorporated to achieve the required strength and workability (slump) characteristics in the M40 concrete, whereas Master Glenium SKY 8866 was used to obtain the desired strength and flow properties in the M60 concrete. The physical properties of these admixtures, as reported by the manufacturer, are presented in Tables 11 and 12. The dosage of the PCE-based superplasticizers was maintained within the manufacturer's recommended range of 0.3% to 1.8% by weight of cementitious material. It should also be noted that the water contained in the admixtures was not considered while calculating the total mixing water added to the concrete.

Table 11: Properties of HRWRA SKY 8650

Properties	Specifications (As per IS 9103)	Value
Aspect	Light to dark brown Liquid	Light to dark brown Liquid
Relative Density	1.06±0.02 at 25°C	1.063
pH	≥6	6.52
Chloride ion Content (%)	< 0.2	0.0030
Dry material content (%)	26±5%	26.47

Table 12: Properties of HRWRA SKY 8866

Properties	Specifications (As per IS 9103)	Value
Aspect	Light to dark brown Liquid	Brown colour liquid
Relative Density	1.06±0.02 at 25°C	1.121 at 25°C
pH	≥6	7.13
Chloride ion Content (%)	< 0.2	0.0035
Solid Content (%)	-	47.96

2.1.6 Water used for mixing and curing

Potable tap water available at CSIR–CRRI, New Delhi, having a pH of 7.2 and conforming to the requirements of IS 456:2000, was used for both mixing and curing of the concrete specimens throughout the study.

2.1.7 EdenCrete Pz7 Carbon Nanotubes (CNT)

As per the test report (lot (s) Number furnished by the client through e-mail dated 22nd June 2026, the physical and chemical characteristics of the supplied Pz7 CNT were determined as follows: specific gravity of 1.036, solids content of 66.55%, pH value of 10.15, and chloride content of 0.031% (measured in accordance with BS EN 480-10:2009 and ASTM C494).

2.2 Mix Proportions and Mixing Procedure

The concrete mix proportions were provided by the client. The final mix compositions for the M40 and M60 OPC-based paving-grade concretes are presented in Tables 13 and 14, respectively.

Table 13: Concrete Mix Proportions for M40 Paving-Grade Concrete

Ingredients	Mix Proportion (kg/m³)			
	Control with fly ash	Control with fly-ash + CNT	Control without fly ash	Control without fly-ash + CNT
	Mix 1	Mix 2	Mix 3	Mix 4
Cement (kg)	360	360	400	400
Fly- Ash	50	50	0	0
Water (kg)	148	148	148	148
W/C	0.36	0.36	0.37	0.37
Sand (kg)	687	687	700	700
20mm (kg)	663	663	671	671
10mm (kg)	663	663	671	671
Super plasticizer	0.6%	0.6%	0.7%	0.7%
CNT	0	250ml/m^3	0	250ml/m^3

Table 14: Concrete Mix Proportions for M60 Paving-Grade Concrete

Ingredients	Mix Proportion (kg/m³)	
	Control with fly-ash	Control with fly-ash + CNT
	Mix 5	Mix 6
Cement (kg)	430	430
Fly-Ash	141	141
Silica Fume	25	25
Water (kg)	161	161
W/C	0.27	0.27
Sand (kg)	809	809
10mm (kg)	936	936
Super plasticizer	0.8%	0.8%
CNT	0	300ml/m^3

The mixing sequence and duration play a critical role in achieving homogeneous paving-grade concrete and significantly influence its fresh- and hardened-state properties. The mixing procedure involves the proper sequencing of aggregates, cementitious materials, water, mineral admixtures (fly ash and silica fume), chemical admixtures, and CNT dosage, along with strict control over the mixing time. Any deviation from the prescribed procedure may adversely affect the performance of the concrete. Initially, the coarse aggregates (20 mm and 10 mm fractions) were introduced into the mixer and dry-mixed for 30 seconds. Subsequently, the fine aggregate was added and dry-mixed for an additional 45 seconds. The cementitious materials, comprising cement, fly ash, and silica fume, were then added, and dry mixing was continued for another 45 seconds, resulting in a total dry-mixing period of approximately 2 minutes. Thereafter, about 65–70% of the total mixing water was gradually added, and wet mixing was carried out for 2 minutes. The mixer was then stopped for 1 minute to allow water to be absorbed by the aggregates, thereby enhancing the effectiveness of the superplasticizer. The remaining 30–35% of the mixing water was separately blended with the required dosage of the PCE-based water-reducing admixture and CNTs, then gradually added to the mixer. Mixing was continued for an additional 5 minutes to ensure uniform dispersion of all constituents and to develop a homogeneous concrete mix. The prepared concrete was subsequently evaluated for its fresh-state properties, including workability and fresh density, and used for casting specimens for the determination of hardened-state properties. Fresh concrete was placed into the moulds in two equal layers, with each layer compacted using a vibrating table for 12 seconds to ensure adequate consolidation.

2.3 Sample Preparation

Concrete specimens of various sizes were cast to evaluate the mechanical and durability properties of the paving-grade concrete. Cube specimens measuring 150 × 150 × 150mm were prepared for compressive strength testing, beam specimens of size 100 × 100 × 500mm were cast for flexural strength determination, and prism specimens measuring 75 × 75 × 285mm were used for the assessment of drying shrinkage. The compressive and flexural strengths of concrete were determined at the ages of 3, 7, and 28 days in accordance with IS 516 (Part 1 / Sec. 1): 2021. Drying shrinkage measurements were carried out after 28 days of curing following the procedures specified in IS 516 (Part 6): 2020. In addition, concrete slab specimens of dimensions 400 × 400 × 100mm were cast for the evaluation of abrasion resistance in accordance with ASTM C779. A total of six concrete mixes, the details of which are presented in Tables 13 and 14, were investigated in the study.

All specimens were de-moulded 24 hours after casting, appropriately identified and marked, and subsequently cured by immersion in water tanks until the designated testing age.

2.4 Test results

2.4.1 Workability

Workability is a critical parameter for pavement-quality concrete used in highway construction. Depending on the construction methodology, workability is generally assessed through slump or compacting factor tests. For semi-mechanized pavement construction, a slump value of 40–60mm is typically specified. Accordingly, the workability of the M40 concrete mixes was determined using the slump test as per IS 1199 (Part 2): 2018 (Figure 2), whereas the flow test was used for the M60 concrete mixes. The average slump and flow values obtained are summarized in Table 15. The results demonstrate that the addition of small quantities of CNT-based admixture (250–300 mL/m³ of concrete) improved the workability of both M40 and M60 paving-grade concrete mixes.

Fig. 2: A typical view of Concrete Mix and Slump Test in progress

Table 15: Slump / Flow Test Values for M40 and M60 Mixes

Slump / Flow, mm					
Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
50-60mm Slump	70-80mm Slump	70-80mm Slump	80-90mm Slump	550mm flow	600mm flow

2.4.2 Fresh and Dry Density

The density of a concrete mix is an indirect indicator of its degree of compaction and the presence of entrapped air voids or pores. In the present study, the fresh density of concrete was determined in accordance with IS 1199 (Part 2): 2018 by measuring the mass of freshly cast and compacted concrete contained in a 150mm cube mould and dividing it by the corresponding volume of the mould. The dry density of the concrete was determined immediately after demolding by dividing the mass of the 150mm cube specimens by their corresponding volume. The results obtained are presented in Table 16. It can be observed that the incorporation of CNTs had no significant effect on either the fresh or dry density of the M40 and M60 paving-grade concrete mixes investigated in this study.

Table 16: Fresh and Dry Density of Concrete Mixes

Test age	Fresh and dry density of concrete mixes, kg/m^3					
	M40 Concrete				M60 Concrete	
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Fresh density	2600	2580	2600	2560	2550	2560
Dry Density	2565	2515	2520	2515	2515	2530

2.4.3 Compressive Strength

Although compressive strength is not directly used in the design of concrete pavement slab thickness, it is an important parameter influencing the overall performance of concrete pavements and is also utilized in the design of dowel bars in accordance with IRC 58: 2015 and IRC 15: 2017. For each paving-grade concrete mix, nine standard cube specimens of size 150 × 150 × 150mm were cast. The specimens were demolded 24 hours after casting and subsequently marked for identification. Thereafter, the cubes were cured by immersion in water tanks at room temperature until the designated testing ages of 3, 7, and 28 days. Compressive strength testing was carried out using a 3000kN capacity compression testing machine (Controls make), as shown in Figure 3, following the procedures specified in IS 1199 (Part 2): 2018 and IS 516 (Part 1 / Sec 1): 2021. The average strength of three specimens was considered as the representative compressive strength of the concrete. The test results for the M40 and M60 concrete mixes are presented in Table 17 and illustrated in Figures 4 and 5.

The results indicate that the incorporation of a very small dosage of CNT significantly improved the compressive strength of concrete, with enhancements of up to 19% compared to the corresponding control mixes. The maximum increase in compressive strength (approximately 19%) was observed in the fly ash-containing mixes (Mix 1 and Mix 2), whereas the minimum improvement (approximately 12%) was recorded in the mixes without fly ash but containing 50 kg/m³ higher cement content (Mix 3 and Mix 4).

A particularly significant observation emerges from the comparison of Mix 2 and Mix 4. Despite containing 50 kg/m³ less cement (approximately 12.5% lower cement content), Mix 2 achieved nearly the same compressive strength as Mix 4 through the combined use of a very low dosage of CNT and partial replacement of cement with fly ash. This finding highlights the potential of CNT-based admixtures to reduce cement consumption while maintaining strength performance, thereby facilitating the development of more cost-effective and environmentally sustainable concrete mixtures for pavement applications.

Table 17: Compressive Strength of Concrete Mixes

Test age	Compressive Strength of concrete mixes, MPa					
	M40 Concrete				M60 Concrete	
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
3 days	30.65	35.22	31.54	35.30	44.4	45.9
7 days	39.30	46.61	40.34	43.6	56.9	57.2
28 days	49.50	55.10	51.70	54.00	62.1	70.2

Fig. 3: A typical view of Compressive Strength Test in progress

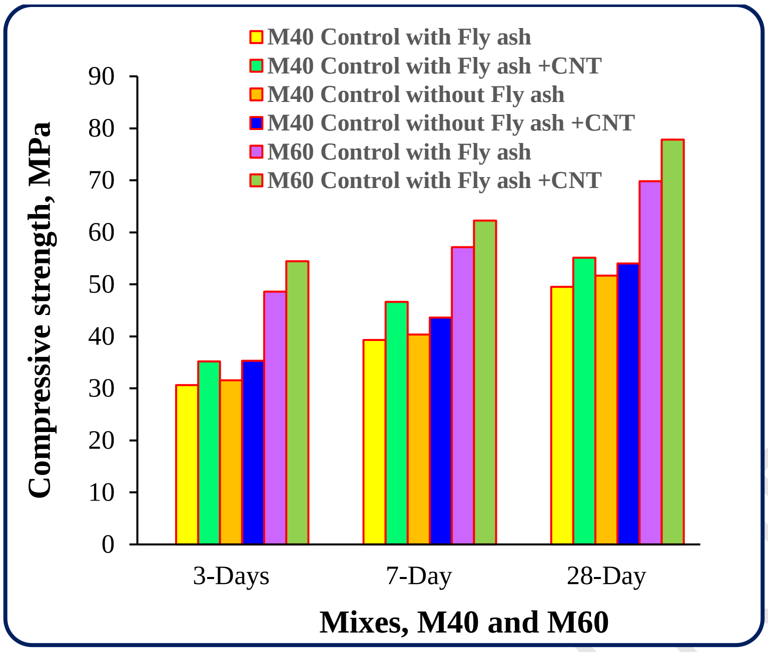

Fig. 4: Compressive Strength of Concrete Mixes at different ages

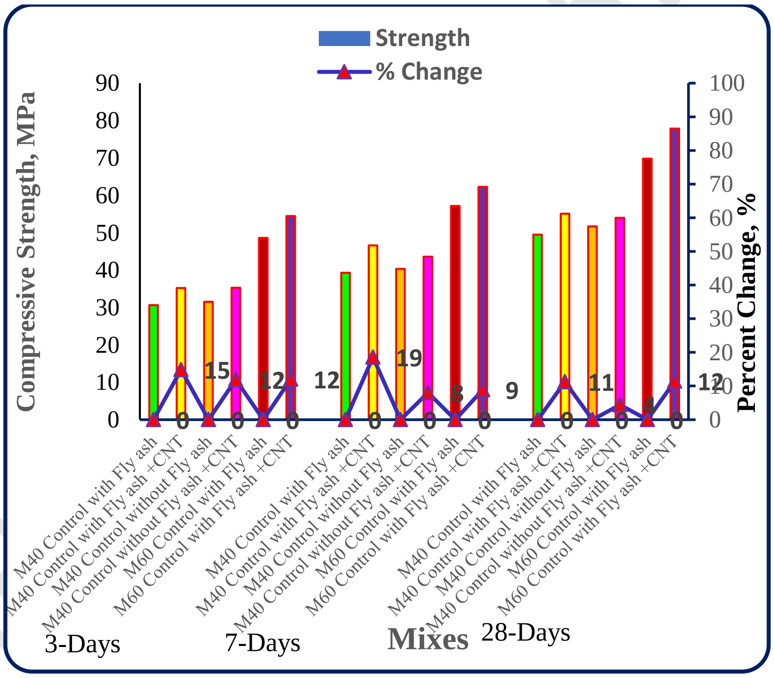

Fig. 5: Percent Increase in Compressive Strength of Concrete Mixes at different ages

2.4.4 Flexural Strength

The flexural strength of concrete is the primary design parameter governing the thickness of rigid pavement slabs. To evaluate this property, nine beam specimens of dimensions 100 × 100 × 500mm were cast from each paving-grade concrete mix. The specimens were demolded 24 hours after casting and subsequently cured by immersion in water tanks at room temperature until the designated testing ages of 3, 7, and 28 days. Flexural strength testing was carried out under third-point loading using a flexural testing machine (Controls make, 1000 kN capacity), as shown in Figure 6, in accordance with the procedures specified in IS 1199 (Part 2): 2018 and IS 516 (Part 1 / Sec 1): 2021. The average value obtained from three beam specimens was taken as the representative flexural strength of the concrete. The test results are presented in Table 18 and graphically illustrated in Figure 7.

The results demonstrate that incorporating a very small dosage of CNT significantly improved the flexural strength of concrete, with enhancements of up to 14% compared to the corresponding control mixes. The maximum increase in flexural strength was observed in the fly ash-containing mixes (Mix 1 and Mix 2), whereas the minimum improvement, approximately 11%, was recorded in the mixes without fly ash but containing 50 kg/m^3 higher cement content (Mix 3 and Mix 4). A particularly noteworthy observation emerges from comparing Mix 2 and Mix 4. Despite containing 50 kg/m^3 less cement (approximately 12.5% lower cement content), Mix 2 achieved nearly 30% higher flexural strength than Mix 4 through the combined use of a very low dosage of CNT and partial replacement of cement with fly ash. The findings indicate that the synergistic interaction between fly ash and CNT is instrumental in achieving the maximum enhancement in concrete performance. It is also noteworthy that, consistent with the compressive strength results, the influence of CNT on flexural strength was more pronounced in the M40 paving-grade concrete mixes, yielding strength gains of up to 14%. In contrast, the corresponding improvement in the M60 concrete mixes was limited to approximately 7%, indicating a relatively greater effectiveness of CNT in moderate-strength concrete systems. This finding highlights the potential of CNT-based admixtures to reduce cement consumption while simultaneously enhancing flexural performance, thereby contributing to the development of more economical and environmentally sustainable concrete mixtures for rigid pavement applications.

Table 18: Flexural Strength of Concrete Mixes

Test age	Flexural Strength (MPa) of concrete mixes					
	M40 Concrete				M60 Concrete	
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
3 days	4.05	4.58	3.64	4.05	6.34	6.80
7 days	4.85	5.34	4.95	5.3	7.13	7.51
28 days	6.24	7.11	5.4	5.73	7.96	8.33

Fig. 6: A typical view of Flexural Strength Test in progress

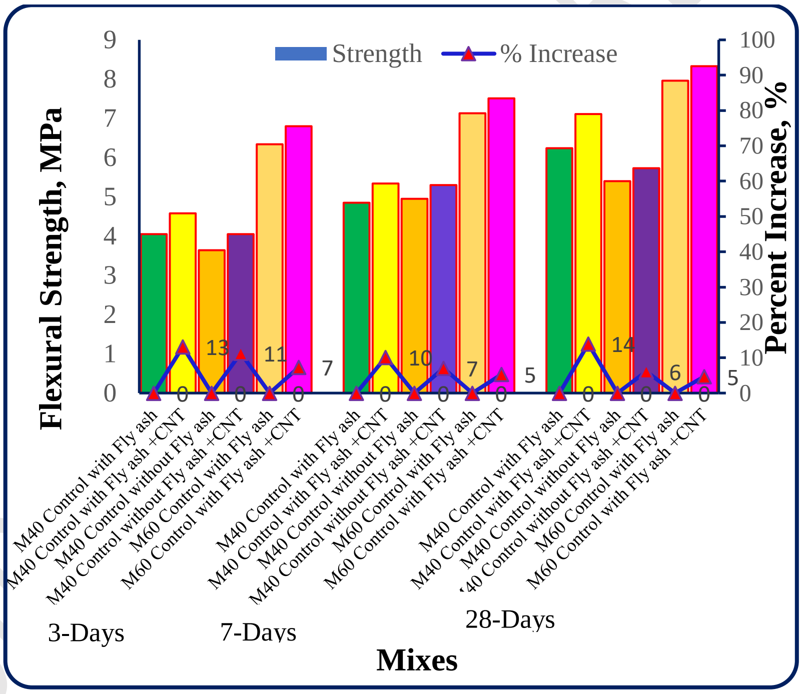

Fig. 7: Flexural strength of Concrete Mixes and Percent Increase at different ages

2.4.5. Split Tensile Strength

The Pavement Mechanistic–Empirical (ME) Design Guide developed by the American Association of State Highway and Transportation Officials (AASHTO) considers the splitting tensile strength of concrete as an important input parameter for pavement design. To evaluate this property, three cylindrical specimens measuring 150mm in diameter and 300mm in height were cast from each paving-grade concrete mix. The specimens were demolded 24 hours after casting and subsequently marked for identification. Thereafter, the cylinders were cured by immersion in water tanks until the testing age of 28 days. The splitting tensile strength of the concrete specimens was determined using a 3000kN capacity compression testing machine (Controls make), as shown in Figure 8, in accordance with the procedures specified in IS 1199 (Part 2): 2018 and IS 516 (Part 1 / Sec 1): 2021. The average value obtained from three specimens was taken as the representative splitting tensile strength of the concrete. The test results are presented in Table 19.

The results indicate that incorporating CNTs had a relatively limited influence on the splitting tensile strength of concrete, with improvements of up to approximately 5% compared to the corresponding control mixes. Nevertheless, the findings suggest that the presence of fly ash is important for maximizing the beneficial effects of CNT incorporation. Similar to the trends observed for compressive and flexural strengths, the influence of CNTs was more pronounced in the M40 paving-grade concrete mixes than in the M60 mixes. The maximum enhancement in splitting tensile strength was observed in the M40 concrete, whereas the corresponding improvement in the M60 concrete was limited to approximately 2%.

Overall, the results indicate that CNTs contribute more significantly to compressive and flexural strength enhancement than to splitting tensile strength development, particularly when used in conjunction with fly ash-containing concrete mixtures.

Fig. 8: A typical view of Split Tensile Strength Test in progress

Table 19: Split Tensile Strength of Concrete Mixes

Test age	Split Strength (MPa) of concrete mixes					
	M40 Concrete				M60 Concrete	
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
28 days	4.45	4.65	4.72	4.83	5.02	5.13

2.4.6 Abrasion resistance of concrete by horizontal slab method (ASTM C 779)

Concrete pavements are continuously subjected to abrasive forces arising from the rolling action of airborne particles and the braking, skidding, acceleration, and sliding of vehicle tyres. Consequently, the abrasion resistance of the concrete surface is an important parameter influencing pavement durability, service life, and the safety of road users. The abrasion resistance of the paving-grade concrete mixes was evaluated using the procedure described below. Concrete slab specimens measuring 400 × 400 × 100mm were cast from each concrete mix. Abrasion testing was performed after 28 days of curing in accordance with ASTM C779-2010. Figure 9 shows the abrasion testing machine used for determining abrasion loss in terms of depth. During the test, the initial abrasion depth was measured after 5 minutes of testing, while the final abrasion depth was recorded after an additional 60 minutes of abrasion. Measurements were obtained using a micrometer, and twenty readings were taken along two perpendicular directions within a circular test area, as illustrated in Figure 10. The abrasion loss of a specimen was calculated as the difference between the average final depth and the average initial depth. A greater abrasion depth corresponds to lower abrasion resistance, whereas a reduction in abrasion depth relative to the control mix indicates improved abrasion resistance. The test results are presented in Table 20 and graphically illustrated in Figure 11.

The results demonstrate that the incorporation of a very small dosage of CNT significantly enhanced the abrasion resistance of concrete, reducing abrasion loss by up to 28% compared with the corresponding control mixes. The maximum improvement was observed in the fly ash-containing concrete mixes (Mix 1 and Mix 2), whereas the minimum reduction in abrasion loss, approximately 15%, was recorded in the mixes without fly ash (Mix 3 and Mix 4).

A particularly noteworthy observation emerges from the comparison between Mix 2 and Mix 4. Despite containing 50 kg/m³ less cement (approximately 12.5% lower cement content), Mix 2 exhibited nearly 28% lower abrasion loss than Mix 4 due to the combined effect of a very low CNT dosage and partial replacement of cement with fly ash. This finding highlights the potential of CNT-based admixtures to reduce cement consumption while simultaneously improving abrasion resistance, thereby facilitating the development of more economical and environmentally sustainable concrete mixtures.

The results further indicate that the presence of fly ash plays a crucial role in maximizing the beneficial effects of CNT incorporation. It is also noteworthy that CNT addition produced a similar reduction in abrasion loss (approximately 28%) in both M40 and M60 paving-grade concretes. This observation suggests that the effectiveness of CNTs in enhancing abrasion resistance is largely independent of the concrete strength grade and is primarily associated with improvements in the microstructure of the cementitious matrix.

Fig. 9: Horizontal Concrete Slab under Abrasion Resistance Test

Fig. 10: A typical view of a Concrete Slab after an Abrasion Test

Table 20: Effect of Different Mixes on the Abrasion Depth of Concrete

Grade of Concrete	Mix Nos	Abrasion Depth (mm)
M40	Mix 1	0.335
	Mix 2	0.24
	Mix 3	0.33
	Mix 4	0.28
M60	Mix 5	0.25
	Mix 6	0.18

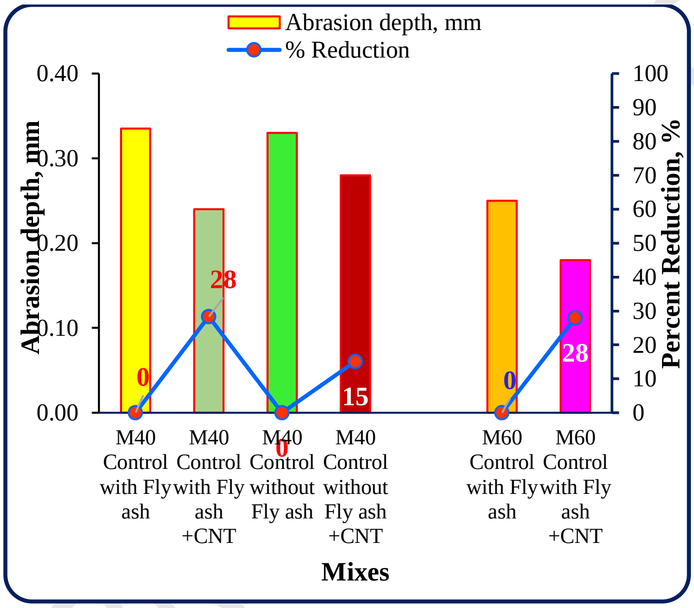

Fig. 11: Abrasion Depth of Different Concrete Mixes

2.4.7 Drying Shrinkage of Concrete

Concrete pavements have a large exposed surface area, making them susceptible to moisture loss and the consequent development of tensile stresses. When the resulting shrinkage is restrained, these tensile stresses can lead to random cracking in both the plastic and hardened states of concrete. Depending on the severity of cracking, the service life of the pavement may be significantly reduced, necessitating repair or rehabilitation. In severe cases, immediate corrective measures may be required (ACI 209R-1992). Moreover, repair and rehabilitation of concrete pavements are generally more complex and costly than those of flexible pavements. Therefore, drying shrinkage is considered an important durability parameter for pavement concrete and is primarily influenced by the water-to-cement ratio, constituent materials, and curing conditions. To evaluate the drying shrinkage characteristics of the paving-grade concrete mixes, standard prism specimens measuring 75 × 75 × 285mm were cast in accordance with the procedures specified in IS 516 (Part 6): 2020. Stainless steel gauge studs were embedded at the centre of the end faces of each specimen to facilitate accurate length measurements using a length comparator. Following 28 days of water curing, the initial length of each prism specimen was measured, as shown in Figure 12.

Subsequently, the specimens were placed in an oven maintained at a temperature of 50 ± 1°C. The specimens were subjected to repeated cycles of drying (minimum 44 hours), cooling (minimum 4 hours), and length measurement until a constant length was achieved. Constant length was considered to have been attained when the difference between two consecutive measurements was less than 0.02 mm. The drying shrinkage was calculated as the difference between the initial wet length and the final dry length and expressed in terms of microstrain.

The drying shrinkage results obtained for the various concrete mixes are presented in Table 21 and graphically illustrated in Figure 13. The results demonstrate that incorporating a very small dosage of CNT significantly reduced the drying-shrinkage of concrete, with reduction of up to 25% compared to the corresponding control mixes. The maximum reduction in drying-shrinkage was observed in the fly ash-containing mixes (Mix 1 and Mix 2), whereas the minimum reduction, approximately 17%, was recorded in the mixes without fly ash but containing 50 kg/m³ higher cement content (Mix 3 and Mix 4). A particularly noteworthy observation emerges from comparing Mix 2 and Mix 4. Despite containing 50 kg/m³ less cement (approximately 12.5% lower cement content), Mix 2 achieved nearly 28% lesser drying shrinkage than Mix 4 through the combined use of a very low dosage of CNT and partial replacement of cement with fly ash. The findings indicate that the synergistic interaction between fly ash and CNT is instrumental in achieving the maximum enhancement in concrete performance. It is also noteworthy that, consistent with the compressive and flexural strength results, the influence of CNT on reduction in drying shrinkage was more pronounced in the M40 paving-grade concrete mixes, yielding reduced drying shrinkage of up to 25%. In contrast, the corresponding improvement in the M60 concrete mixes was limited to approximately 13%, indicating a relatively greater effectiveness of CNT in moderate-strength concrete systems. This finding highlights the potential of CNT-based admixtures to reduce cement consumption while simultaneously enhancing flexural performance, thereby contributing to the development of more economical and environmentally sustainable concrete mixtures for rigid pavement applications.

Table 21: Effect of Different Mixes on the Drying Shrinkage of Concrete

Grade of Concrete	Mix Nos.	Average Drying shrinkage, mm	Drying Shrinkage, %
M40	Mix 1	0.128	0.051
	Mix 2	0.096	0.038
	Mix 3	0.161	0.064
	Mix 4	0.134	0.054
M60	Mix 5	0.101	0.040
	Mix 6	0.088	0.035

Fig. 12: A typical view of Drying Shrinkage Test in progress

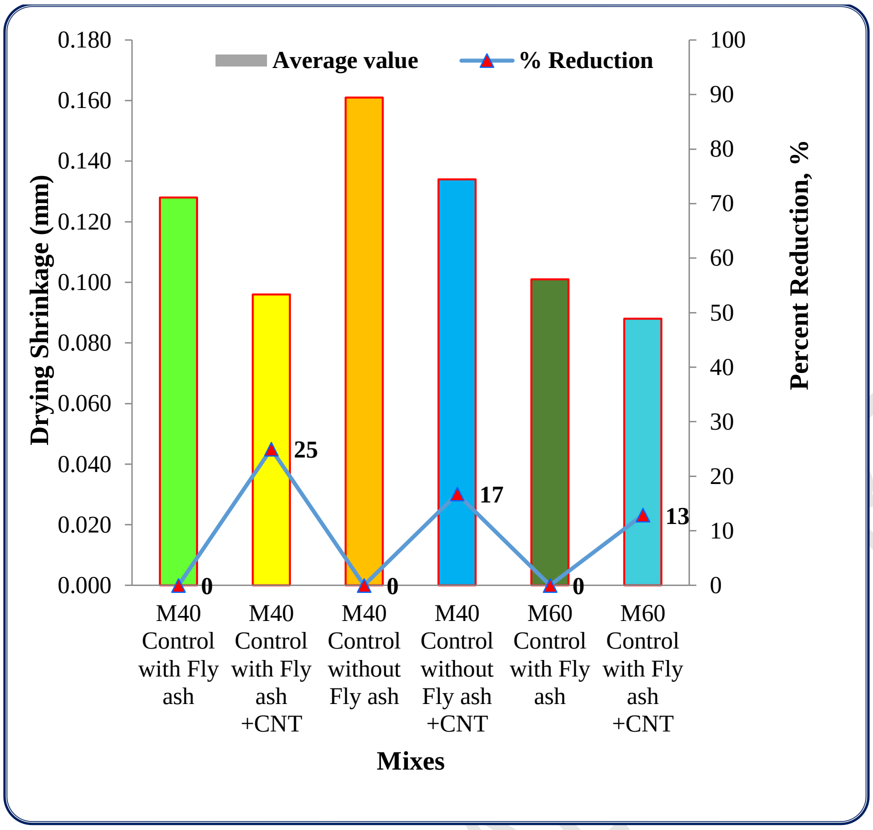

Fig. 13: **Drying Shrinkage of Different Concrete Mixes**

3. CONCLUSIONS

The following conclusions may be drawn from the present study:

1. The incorporation of carbon nanotubes (CNT) resulted in a slight improvement in the workability of paving-grade concrete mixes.
2. The inclusion of CNT had no significant effect on the fresh or dry density of the paving-grade concrete mixes.
3. The incorporation of CNT significantly enhanced the compressive strength of concrete, with improvements of up to 19% compared to the corresponding control mixes.
4. The flexural strength of concrete was improved by up to 14% through the incorporation of CNT. The maximum increase was observed in the fly ash-containing mixes, while the minimum improvement, approximately 11%, was recorded in the mixes without fly ash but containing 50 kg/m³ higher cement content.

5. The influence of CNT on the splitting tensile strength of concrete was relatively limited, with improvements of up to approximately 5% compared to the corresponding control mixes.
6. CNT incorporation significantly improved the abrasion resistance of concrete, reducing abrasion loss by up to 28% compared to the corresponding control mixes. The maximum enhancement was observed in the fly ash-containing concrete mixes, whereas the minimum reduction in abrasion loss, approximately 15%, was recorded in the mixes without fly ash.
7. The incorporation of CNT significantly reduced the drying-shrinkage of concrete, with reduction of up to 25% compared to the corresponding control mixes. The maximum reduction in drying-shrinkage was observed in the fly ash-containing mixes, whereas the minimum reduction, approximately 17%, was recorded in the mixes without fly ash but containing 50 kg/m³ higher cement content.
8. The results indicate that the presence of fly ash plays a crucial role in maximizing the beneficial effects of CNT incorporation in concrete.
9. The findings further demonstrate that the synergistic interaction between fly ash and CNT is instrumental in achieving the greatest improvements in concrete performance.
10. The study highlights the potential of CNT-based admixtures to reduce cement consumption while maintaining the required strength and durability characteristics. This offers a promising approach for developing cost-effective and environmentally sustainable concrete mixtures for pavement applications.

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