# Non-Destructive Evaluation of Cement Mortar Quality with Hyperspectral Remote Sensing Methods

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## Abstract

Cement mortar is a fundamental material in construction, with its strength and durability influenced by mix proportions and curing conditions. This study investigates the spectral characteristics and compressive strength of cement mortar mixes with varying cement-to-sand ratios (1:3, 1:4, and 1:6) over curing periods of 7 and 14 days. Utilising an SVC HR-1024i field spectroradiometer, spectral reflectance measurements were conducted to assess the surface properties of mortar cubes, while compressive strength tests were performed using a Universal Testing Machine. Results demonstrate a strong correlation between mix composition, curing duration, and both reflectance and strength developed with time. Higher cement content resulted in increased compressive strength and reflectance, particularly on the top surfaces of the samples. Further, spectral reflectance values increased with curing time. It may indicate the influence of hydration and microstructural densification on surface characteristics. Overall, this research introduces spectral analysis as a non-destructive method for evaluating mortar quality. It also offers a practical alternative to hectic and time-consuming traditional strength testing approaches. By highlighting the significant differences in reflectance based on mix proportions and curing conditions, the findings can contribute to improved quality control in construction materials. It can promote further exploration of non-destructive testing methodologies in this field.

## 1. Introduction

Concrete and mortar are fundamental building materials in the construction industry. These materials are basically recognized for their durability, strength, and versatility. These properties directly contribute to the quality of building structures (Domone and Illston, 2018; Kolhe et al., 2024). Further, the properties of construction materials like cement mortar are continuously influenced by a variety of interacting factors. A comprehensive understanding of building material properties is essential for carrying out any construction activity. These properties can be classified broadly into physical, mechanical, chemical, electrical, magnetic, and thermal categories (Duggal, 2017). Physical properties encompass porosity, durability, water absorption, density, and resistance to weathering (Fernando et al., 2023; Kodur and Harmathy, 2016). Mechanical properties of materials include strength, hardness, elasticity, plasticity, toughness, ductility, and fatigue resistance, defining their performance under various stresses and loads (Ashby and Jones, 2012; François et al., 1998). Chemical properties include resistance to corrosion and other chemical reactions (Pacheco-Torgal et al., 2012; Ruscher et al., 2011). Electrical properties cover the electrical resistance or conductivity of different materials (Hlaváčová, 2007; Honorio et al., 2020). Further, magnetic and thermal properties encompass magnetic permeability, thermal capacity, conductivity, and resistivity, which depend on the molecular configuration and interaction with other particles (Balaji et al., 2014; Meukam et al., 2004). These factors have the potential to change their fundamental characteristics over time by inducing a chain reaction that can affect the material's overall quality (Bertolini et al., 2013; Carlsson et al., 2014; Jiang et al., 2022; Joshaghani et al., 2018; Kumar and Sharma, 2024; Mishra and Sharma, 2024; Papadakis et al., 1991).

Traditionally, rigorous tests based on established standards and guidelines are conducted on material samples to access its quality (Gdoutos and Konsta-Gdoutos, 2024; Hooton, 2019; Popovics, 1992). Compressive strength testing has long been the primary method for assessing mortar quality. However, this approach has notable limitations, as it is both time-consuming and requires the destruction of samples (Beushausen et al., 2019; Wang et al., 2020). Modern technologies now offer practical solutions to the limitations of traditional construction material testing methods, especially in terms of speed. It also maintains efficiency and enhances the level of detail in the analysis. Ultrasonic testing in building materials utilizes high-frequency sound waves to evaluate the integrity, density, and internal structure of materials, offering critical insights into their quality and potential defects without causing damage (Karaiskos et al., 2015; Washer et al., 2004). Similarly, X-ray tomography employs X-ray imaging to generate detailed cross-sectional images of materials, facilitating the visualization of internal features and defects, thereby enabling comprehensive analysis of material structure and integrity without the need for destructive sampling (du Plessis and Boshoff, 2019; Vicente et al., 2019).

Remote sensing plays a key role in multi-disaster assessment, material identification and testing, rock studies etc. (Ali et al., 2022; Farhan et al., 2024; Feng et al., 2025; Jefriza et al., 2020; Pritipadmaja et al., 2023; Rai and Singh, 2023; Srivastava et al., 2025; Stead et al., 2019; Tang et al., 2024; Tarpanelli et al., 2022; Thakur et al., 2025, 2024; Verma and Vijay, 2024). It is also a prominent non-destructive approach and provides substantial advantages over conventional testing techniques (Cavalli et al., 2011; El Masri and Rakha, 2020; Fan et al., 2020; Gagliardi et al., 2023). This technology facilitates efficient data collection across multiple scales and resolutions. It leverages high-speed computing for rapid data processing and analysis, significantly reducing the need for extensive fieldwork. By utilizing various wavelengths of the spectrum, it captures a wide range of information about objects from remotely sensed data (Ahmed et al., 2024; Chang, 1999; Martínez et al., 2024; Shaban, 2013). The spectral reflectance of composite materials serves as a unique signature, enabling the quantitative prediction of their constituents and properties. A range of spectral measurement devices—including radiometers, spectro-radiometers, and nuclear magnetic resonance—along with spectroscopy techniques like Fourier Transform Infrared Spectroscopy, can be employed to gather detailed information about various objects (Brook and Ben-Dor, 2011; Roberts and Herold, 2004). These advanced methods allow for precise characterization and analysis, enhancing our understanding of material composition and behaviour in diverse applications. By integrating these technologies, researchers can achieve more accurate assessments and insights into material properties.

In all previous research, certain research gaps have not been addressed. Non-destructive techniques have not been widely studied for assessing chemical and microstructural changes in construction materials over time. Spectral analysis has not been fully implemented to directly predict mechanical properties, such as strength and durability. Remote sensing is largely used for large-scale monitoring, with limited adaptation for in-situ testing of smaller materials. Additionally, the need for advanced data models to efficiently process high-resolution data and validate spectral methods as reliable alternatives to destructive testing has not been widely explored. This paper addresses key gaps by introducing spectral analysis as a non-destructive method for assessing mortar strength and composition, traditionally evaluated through destructive compressive tests. It explores how spectral properties correlate with mix ratios and curing progress, providing a new way to monitor hydration and material consistency over time. Additionally, the study demonstrates the novel application of remote sensing techniques in construction quality control. It can provide a practical tool for identifying inconsistencies in mortar composition and enhancing sustainable testing practices.

## 2. Data and Experiment methods

### 2.1 Instrumental Setup


Figure 1. Screen of the spectroradiometer showing the spectral signature of mortar sample.

Spectral measurements were conducted with the SVC HR-1024i field spectroradiometer, capable of capturing the UV, visible, and near-infrared (NIR) regions spanning 350 nm to 2500 nm (Figure 1). This device uses an integrated setup of three diffraction grating spectrometers, one featuring a silicon array and two using indium gallium arsenide (InGaAs) diode arrays. The silicon array comprises 512 discrete detectors, while each InGaAs array is equipped with 256 detectors, collectively allowing for high-resolution readings across 1024 spectral bands.

To ensure accuracy, rigorous calibration procedures—encompassing wavelength, radiometric, and field of view adjustments—are pre-configured by the manufacturer, using specialized software to optimize each measurement's calibration parameters. This calibration ensures that the sensor precisely converts received electromagnetic radiation into electronic signals. Data collected during measurements is immediately downloaded and stored on a computer through the instrument's dedicated PC Data Acquisition Software, supporting seamless data handling and analysis.

### 2.2 Methodology

For evaluating the quality of cement mortar mixes, mortar cubes measuring 70.6 x 70.6 x 70.6 mm were prepared.

Ordinary Portland Cement (OPC) was used, with mix proportions set at 1:3, 1:4, and 1:6 to represent different cement-to-sand ratios (Figure 2). The preparation of these mortar mixes adhered to the standards specified in IS: 4031 Part 6, which governs the methods for testing cement. Further, the water-cement ratio was adjusted for each mix to maintain workability and meet the desired quality parameters. For the 1:3 mix proportion, a water-cement ratio of 0.4 was used; for the 1:4 mix, the ratio was increased to 0.5, and for the 1:6 mix, a water-cement ratio of 0.7 was employed.

Figure 2. Sample of Ordinary portland cement(OPC).

To achieve uniformity in the mix, standard sand as per IS:650, in Grades I, II, and III, was used in casting the mortar cubes. A total of 15 mortar samples were prepared, allowing for multiple trials in strength and quality assessments. Detailed specifications, including mix proportions, water-cement ratios, and sand grading, are presented in Table 1. These specifications provide a comprehensive basis for assessing the structural and durability properties of the mortar under various mix conditions, essential for quality control in construction applications.

Table 1: Mortar Mix Design Specifications

| Mortar mix ratio | 1:3 | 1:4 | 1:6 |
|---|---|---|---|
| Cement type | OPC | OPC | OPC |
| Mass of cement (g) | 200 | 200 | 200 |
| Mass of fine aggregate (g) | 600 | 800 | 1200 |
| Volume of water (ml) | 80 | 100 | 140 |
| Water-cement ratio | 0.4 | 0.5 | 0.7 |

After thoroughly mixing the mortar, it was placed into standardized cube molds and compacted using a vibrating machine, which operated at a frequency of 12,000 ± 400 vibrations per minute. The machine provided consistent compaction for 2 minutes, ensuring a uniform mix with minimized air pockets within the mortar cubes. Following the compaction, the mortar samples were left to set in their molds for 24 hours, allowing the initial hardening process to take place. Once the initial setting period was complete, the cubes were carefully removed from the molds and submerged in water for the curing process, which promotes hydration and strength development in the cement mortar. Curing durations were set at 7 and 14 days, during which the samples were periodically checked to ensure they remained fully submerged, thus maintaining the ideal conditions for optimal strength gain.

Prior to performing compressive strength tests, spectral reflectance measurements were recorded for each of the six faces of the mortar cubes. This data collection allowed for a comprehensive analysis of the surface characteristics, potentially correlating surface reflectance with compressive strength development. The compressive strength of each mortar cube was then measured using a Universal Testing Machine (UTM) with a maximum capacity of 2000 kN. The UTM applied a gradual load at a rate of 35 N/mm² per minute, as recommended by IS:4031 Part 6, to ensure accurate measurement of the mortar's compressive strength. The tests, conducted after the 7-day and 14-day curing periods, provided insight into the progressive strength development of each mix, as shown in Figure 3.


Figure 3. Mortar Samples prepared in the laboratory. Moulding date and mix ratio are indicated over the samples.

## 3. Results and Discussions

The study analyzed spectral characteristics and compressive strength of three different cement mortar mixes. Table 2 presents the compressive strength and reflectance values for different mix ratios (1:3, 1:4, and 1:6) at curing ages of 7 and 14 days. The data highlights distinct trends in both strength and reflectance patterns related to mix composition and curing duration. The spectral reflectance data, illustrated in Figure 4, revealed distinct spectral patterns for each mix. This variability in spectral response highlights the influence of curing duration and mix proportions on the reflectance properties of mortar.

Table 2: Mortar compressive strength and the reflectance values for different curing ages

| Mortar Mix Ratio | Curing Age (Days) | Compressive Strength (Mpa) | Mortar Top Face Reflectance (%) | | Mortar Bottom Face Reflectance (%) | |
|---|---|---|---|---|---|---|
| | | | Max | Min | Max | Min |
| 1:3 | 7 | 35.71 | 46.27 | 28.52 | 33.19 | 26.37 |
| | 14 | 37.61 | 47.89 | 26.95 | 21.88 | 15.03 |
| 1:4 | 7 | 22.61 | 39.04 | 27.30 | 31.24 | 23.69 |
| | 14 | 22.97 | 39.15 | 31.71 | 27.41 | 21.52 |
| 1:6 | 7 | 10.29 | 30.52 | 21.61 | 21.60 | 15.70 |
| | 14 | 7.28 | 38.70 | 26.99 | 20.88 | 14.79 |

The 1:3 mix, with the highest cement content, shows the highest compressive strength at both 7 and 14 days. The value reached 35.71 MPa and 37.61 MPa, respectively. In contrast, the 1:6 mix, which has the lowest cement content, shows significantly lower strengths (10.29 MPa at 7 days, dropping to 7.28 MPa at 14 days). The high cement-to-sand ratio in the 1:3 mix contributes to greater strength and reduced porosity, which also impacts reflectance.

Reflectance values generally increase with curing age, especially on the top faces of the samples. This trend is attributed to the densification of the mortar's microstructure during hydration, which reduces surface roughness and increases reflectivity. For example, the maximum top face reflectance of the 1:3 mortar increases slightly from 46.27% to 47.89% between 7 and 14 days. This reflects the continuous hydration process, which strengthens the structure and influences the surface's ability to reflect light.

Reflectance values are consistently higher on the top faces compared to the bottom faces, especially for mixes with higher cement content. The top face of the 1:3 mix, for instance, shows a maximum reflectance of 47.89% at 14 days, while the bottom face reaches only 33.19%. This variation is likely due to differences in surface exposure; the top face is more exposed to curing conditions, while the bottom face may have more moisture retention and less uniform curing, affecting its texture and, consequently, reflectance.

Mixes with higher sand content, like the 1:6 mix, exhibit lower compressive strength and less reflectance on both top and bottom faces. The increase in sand dilutes the cement matrix, creating more porous and rougher surfaces, which tend to absorb more light, resulting in lower reflectance values. At 14 days, for example, the top face reflectance for the 1:6 mix is 38.70%, considerably lower than the 47.89% of the 1:3 mix. This also suggests that as the sand content increases, there is a less compact structure, affecting both strength and reflectance properties.


Figure 4. Spectral Response of different Mortar mix.

At the 14-day curing mark, the mortar mix with a 1:3 proportion displayed the highest reflectance on its top face, reaching 47.89%, whereas its bottom face showed a significantly lower reflectance of 21.88%. The 1:4 mix exhibited a top face reflectance of 39.15%, with the bottom face measuring 27.41%. Similarly, for the 1:6 mix, the top face reached a maximum reflectance of 38.70%, compared to a lower 20.88% reflectance on the bottom face. These differences in reflectance between the top and bottom faces likely reflect variations in material density and curing conditions.

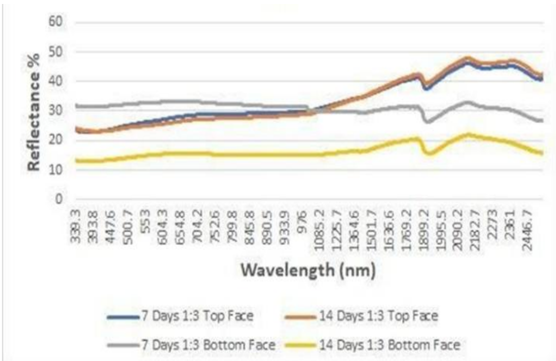


Figure 5. Spectral Reflectance of 1:3 Mortar at Various Days of Curing

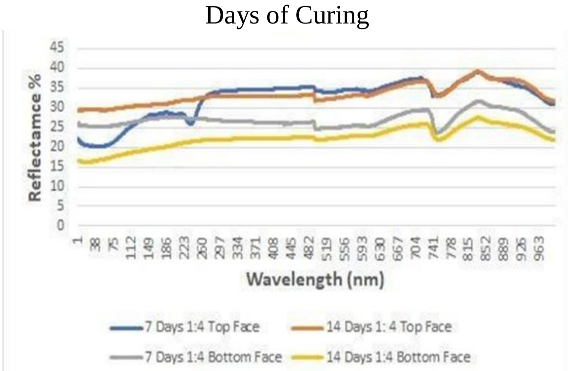


Figure 6. Spectral Reflectance of 1:4 Mortar at Various Days of Curing


https://doi.org/10.5194/isprs-archives-XLVIII-G-2025-71-2025 

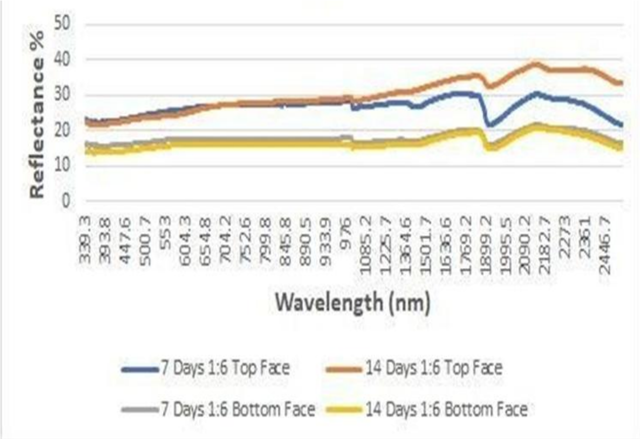


Figure 7. Spectral Reflectance of 1:6 Mortar at Various Days of Curing

Figures 5, 6, and 7 illustrate how spectral reflectance changes with curing age for each mortar mix. Across all mixes, an increase in reflectance was observed as curing progressed, though this increase was more gradual for mortar mixes compared to concrete. Specifically, the 1:3 and 1:4 mortar mixes showed only minor changes in spectral reflectance between the 7th and 14th days. In contrast, the 1:6 mix displayed a more noticeable rise in reflectance over time, corresponding to its higher water-cement ratio and lower compressive strength.

The study's findings highlight that the spectral properties of mortar are influenced by curing age and mix proportions, which affect surface reflectance characteristics. This non-destructive approach offers an effective alternative to traditional compressive strength testing, allowing for a preliminary assessment of mortar strength and composition based on surface reflectance. Furthermore, the noticeable differences in reflectance between the top and bottom faces of the cubes underscore the influence of material placement and curing conditions. These insights provide a potential method for distinguishing between different mortar types and evaluating their structural properties through spectral reflectance analysis.

## 4. Conclusion

This study provides valuable insights into the spectral behaviour of different cement mortar mixes (1:3, 1:4, and 1:6) as they undergo curing. The findings demonstrate that mortar mixes with higher cement-to-sand ratios exhibit more pronounced differences in reflectance patterns between the top and bottom faces of the cubes, highlighting the impact of mix composition on spectral properties. Over time, an increase in reflectance was observed across most mortar types, correlating with progressive changes in compressive strength. This trend suggests that as curing advances, the hydration process leads to microstructural densification, which influences the surface reflectance properties. These variations in spectral characteristics not only reflect the influence of different material compositions and water-cement ratios but also underscore the sensitivity of spectral analysis as a tool to detect subtle changes in mortar quality during curing.

The significance of this study lies in its introduction of spectral analysis as a non-destructive, practical approach to monitor mortar strength and composition. Traditionally, compressive strength testing has been the standard for assessing the structural properties of cementitious materials, but it is both time-consuming and destructive. By using spectral reflectance as a proxy for strength and composition assessment, this study opens avenues for more efficient and sustainable testing methods that preserve the integrity of the mortar samples. The unique approach of capturing spectral responses at different curing stages presents a novel contribution to the field, providing a viable alternative for quality control in construction and material science. The ability to differentiate between mortar types based on their spectral properties could also serve as a powerful tool for identifying inconsistencies or deviations in mix composition, ultimately supporting more resilient construction practices and advancing research in non-destructive testing techniques.

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