STUDY OF ELECTROMAGNETIC RADIATION FROM CEMENT AND CEMENT BASED COMPOSITES UNDER IMPACT LOADING

A Thesis

submitted

by

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Declaration by the Research Scholar

This is to certify that the thesis entitled **"Study of Electromagnetic Radiation from Cement and Cement based Composites under Impact Loading"** submitted by me to the Indian Institute of Technology, Mandi for the award of the degree of Doctor of Philosophy is a bonafide record of research work carried out by me in the School of Engineering, Indian Institute of Technology, Mandi under the supervision of Dr. Vishal Singh Chauhan and Dr. Rajeev Kumar. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

In keeping with the general practice of reporting scientific observation, due acknowledgements have been made wherever the work described is based on the findings of other investigators.

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Thesis Certificate

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ABSTRACT

Service life of any structure deteriorates due to ageing of materials, excessive use, overloading and other environmental factors. It is imperative to continuously monitor the structure. There are several non-destructive techniques available nowadays, to name a few ultrasonic technique, acoustic emission technique, rebound hammer technique, etc. Also sensors based on fibre optics technique and piezoelectric based monitoring has gained much attention. Emission of electromagnetic radiation (EMR) from different materials was reported by several researchers under different modes of mechanical loading. Now with the discovery of new materials and advancement in instrumentation to detect effects associated with plastic deformation, micro-crack formation and propagation, and fracture, EMR emission effect becomes important because its qualitative and quantitative analysis would help a great deal in understanding the physics of the failure of the material. With the invention of new smart composites, this EMR can be useful for developing non contact sensors. Also there is a need to explore materials which can give maximum EMR signal under minimum stimulus. This element could be embedded in the main material paving the way for the development of smart composites.

However in realising these goals, it is highly essential that the basic knowledge associated with EMR emission be broadened. With this aim in view and considering that cement is the most common structural material and is used indispensably in mortar and concrete for any civil infrastructure, some basic experimental and theoretical investigations on EMR emissions during impact loading in cement, cement based composites, mortar and mortar based composites have been carried out and presented in this dissertation.

The organization of the dissertation has been made as follows:

Chapter I: Introduction

Chapter II: Literature review

Chapter III: Basic Experiments on cement paste, cement flyash composite and cement – metal powder composites under impact load

Chapter IV: Theoretical analysis for the emission of EMR from cement paste under impact load

Chapter V: Effect of addition of piezoelectric material in cement on EMR emissions under impact load

Chapter VI: EMR emissions from cement mortar and cement mortar composites under

impact load

Chapter VII: Conclusions and suggestions for future research

References

In order to make the presentation comprehensive a review of research work on electrical, acoustic, and electromagnetic emissions and the various physical models proposed to explain the mechanism of these emissions by earlier researchers in different materials are presented in chapter II.

The instrumentation system, experimental set up and data acquisition system adopted for the investigations are given in chapter III. An important structural material cement paste has been chosen for the study of EMR under impact load. Cement paste was investigated for general characteristics of EMR emissions under impact load. Also the effect of moisture in cement paste was studied for EMR signals. The EMR emission from cement – flyash composite and cement – metal powder composites have been investigated under impact load. The cement paste samples water cured for different days viz. 3 days, 7 days, 14 days and 28 days respectively were used for the impact test. Experimental results show that for both water cured and oven dried pure cement paste samples (water cured for 28 days and then taken out and oven dried for 6 hours at 100°C), EMR voltage and average energy release rate increases as the height of impact increases (in the range of 6 cm to 21 cm). The maximum peak voltage reduces in the range of 24.24 % to 34.93 % when the samples are tested after drying in oven for 6 hours at 100 ^{0}C. The movement of ions through pores present in cement paste and dipole oscillations are considered responsible for the observed emissions from cement paste. The amplitude of EMR signals decreases with the addition of flyash to cement – flyash samples. Also the compressive strength increases with number of curing days for cement paste while it decreases with the concentration of flyash in cement paste – flyash composites. For the cement – metal powder composites, compressive strength higher than the pure cement is obtained on addition of 1 % of copper or aluminium. However as the percentage of these powders is increased the strength decreases and for 5 % powder fraction strength is lower than that of pure cement. The addition of nickel and zinc tends to reduce the strength. Further for all composites the compressive strength decreases with increase in the fraction of metal powder content. Higher EMR voltages are obtained for all the composites of the metal powders with the cement as compared to the pure cement.

A theoretical model for the EMR emission during impact loading in cement paste has been presented in chapter IV. Cylindrical cement samples cured for 28 days emit EMR in the range of 44 mV to 95 mV as the height of impact is varied from 6 cm to 21 cm. The EMR voltage increases linearly as the height of impact increases. This suggests the suitability of the EMR measurement for the structural health monitoring under dynamic loading conditions. A theoretical model has been presented to explain the occurrence of the EMR under impact. The ions present in the capillary pores of the hydrated cement paste lead to the formation of dipoles at the solid liquid interphase. When impact is applied the separation distance between the opposite charges of the dipoles undergoes transient variation causing the EMR. Derivation of electric field and magnetic field of EMR obtained by Griffiths and Misra et al has been used. Theoretical model developed shows a linearly increasing pattern with the increase in the height of impact. Theoretically calculated EMR voltage matches well with the experimental results in nature as well as magnitude.

Higher amplitude of the EMR signals obtained is desirable for efficient monitoring. Since the EMR was found to have its genesis in the formation of dipoles, effect of adding piezoelectric materials to the cement on EMR was explored because these materials have permanent dipoles. This has been presented in the Chapter V. First of all EMR from lead zirconate titanate (PZT) under impact load has been presented in chapter V A. For the test soft PZT of grade SP 5A and hard PZT of grade SP 4 were chosen. EMR voltage obtained from soft PZT was higher in magnitude as compared to hard PZT. EMR voltage obtained suggests that piezoelectric materials are a potential signal emitting candidate for non-contact sensing applications. Based on this result soft PZT of grade SP 5A was mixed with cement (composites were prepared by replacing 5 %, 10 %, 20 % and 40 % weight of cement by PZT) with the aim to obtain enhanced voltage as compared to cement paste. The generation of EMR from cement – PZT composite has been presented in chapter V B. Cement – PZT composite were characterised for bulk density, porosity, dielectric constant, loss tangent and piezoelectric charge coefficient. These characterisations were done on sample size of 12 mm diameter and 1 mm thickness. For impact on cement – PZT composites, sample size was 22 mm diameter and 22 mm height. The results show that the measurement of bulk density of cement - PZT composites shows an increasing pattern while porosity shows a decreasing pattern with increase in PZT content. Also dielectric constant was observed to be maximum and loss tangent to be the minimum for composite containing 40% PZT. A linear variation in the EMR response of the cement composites with increase in height of impact was obtained. Also addition of even 5 % of PZT causes an increase in the range of 893 % - 557 % in EMR voltage when samples were impacted from a height of 6 cm and 21 cm respectively. Apart from lead based cement composite, lead free cement composite viz. cement – barium titanate (BT) has been studied for EMR emission under impact load in chapter V C. The cement – BT composites were prepared by replacing 5 %, 10 %, 20 % and 40 % weight of cement by PZT with the aim to obtain enhanced voltage as compared to cement paste. The bulk density values of cement – PZT composites was found to be higher than that of cement – BT composites which can be attributed to higher density of PZT particles. The porosity for cement – PZT composite was higher as compared to cement – BT composites. The dielectric constant and loss tangent values obtained for cement – PZT was higher than cement – BT composites. The EMR amplitude was found to be higher at any height of impact in cement – PZT composite as compared to cement – BT composite for any concentration. The addition of 5 % BT enhances the EMR voltage by 318 %.

The study has further been extended on the standard samples (70.6 mm X 70.6 mm X 70.6 mm) of the practically used form of cement that is mortar which is presented in chapter VI A. A comparison of EMR obtained during quasi-static compression of the mortar samples with that during impact has been done. EMR voltage showed decreasing pattern with increase in the number of days of water curing and it also varies inversely with the ultimate crack resistance. Addition of fibres namely coir, sisal and jute in mortar results in higher compressive strength, ultimate crack resistance and crack resistance ratio and the coir fibre gives highest values among these. On the other hand the addition of coir fibre in mortar results in decreased EMR voltage. EMR voltage shows inverse proportionality with ultimate crack resistance and also proportionality with the height of weight drop suggesting the suitability of EMR measurement for structural health monitoring. Compression tests have been carried out on universal testing machine (UTM) with a strain rate of 1 mm/min. The EMR voltage obtained during failure under compression is very less as compared to EMR voltage obtained during impact, substantiating the theory that the genesis of EMR is primarily due to the oscillations of the dipoles formed at capillary pores. Also a theoretical model for the generation of EMR from cement mortar has been presented in this chapter. The theoretical model presented in the Chapter IV has then been modified for the changed geometry of the sample and to include the properties of mortar. The modified model gives results in close agreement with the experimental results. Further with increase in the number of days of curing the EMR voltage shows a decreasing pattern exactly opposite to the increasing ultimate crack resistance. This suggests suitability of this measurement for structural health monitoring.

With an intent to obtain higher amplitudes of EMR voltage the effect of addition of lead zirconate titanate (PZT) of grade SP 5A in mortar was also studied in chapter VI B. The percentage of PZT in mortar varied from 5 % to 40 % by weight of cement. Electromagnetic radiation response from cement mortar, cement mortar – PZT (lead zirconate titanate) and fibre reinforced mortar - PZT under impact loading has been investigated. A linearly increasing pattern of the EMR voltage with the height of impact as well as with increase in percentage of PZT is observed for all the compositions tested suggesting the suitability of this technique for deformation monitoring and structural health monitoring. The inclusion of PZT in mortar results in higher values of compressive strength, ultimate crack resistance and impact crack resistance ratio as compared to plain mortar up to 20 % PZT addition. Beyond 20 % PZT addition these parameters become less than plain cement mortar. To overcome this, possibility of fibre reinforcement was explored. Effect of increase in the distance of antenna from sample shows that EMR voltage attains a constant value after 17 cm and 8 cm respectively for coir fibre reinforced mortar - PZT (20%) and cement mortar respectively when impacted from a height of 21 cm. The results suggest suitability of the EMR measurement for structural health monitoring.

Conclusions and suggestions for future research

Finally, relevant conclusions from the experimental and theoretical studies have been drawn in chapter VII which also includes scopes for future research. A comprehensive list of references has been inserted at the end of the dissertation.

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(Amit Kumar)

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