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Effect of temperature on the accuracy of predicting the damage location of high strength cementitious composites with nano-SiO_2 using EMI method

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ABSTRACT

Recent constructions of large scale infrastructures and structural deterioration of existing buildings have called for an introduction of structural health monitoring (SHM) method. The current SHM method however lacks in applicability, mostly owing to its high cost and practicability [6]. EMI based PZT has been a topic of numerous studies due to its broader application and low cost. Studies on the EMI of metal pipes, composite materials and concrete structures were conducted in late 2000's, while recent studies focus on a means of improving the detection sensitivity of the damage [7]. This paper summarizes a portion of an experimental work conducted by the authors [4] to investigate the influence of the temperature on the accuracy of predicting the damage location of high strength cementitious composites with nano-SiO_2 by means of the neural network method.

1. INTRODUCTION

Up to date, a relatively new non-destructive evaluation technique known as the electro-mechanical impedance (EMI) method has been studied by many researchers. EMI method utilizes a single piezoelectric material to act as an actuator and a sensor simultaneously [9]. The PZT acting as an actuator vibrates a host structure by a function generator while the PZT acting as a sensor detects the vibration of the host structure [10]. When the integrity of the host structure is damaged, the vibration changes and it can be observed by means of impedance measuring [10]. Oscilloscope

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is used to measure electrical impedance of the PZT element [10]. Eq. (1) shows the relationship between the electrical impedance and mechanical impedance of the PZT and the structure [5].

$$\mathrm{Y}(\omega) = i\omega a(\varepsilon_{33}^{T}(1 - i\delta) - \frac{Z_s(\omega)}{Z_s(\omega)+Z_a(\omega)} d_{3x}^{2}\bar{Y}_{xx}^{E}) \qquad (1)$$

Here, $\mathrm{Y}(\omega)$ is electrical admittance (inverse of impedance) of the PZT element, and $Z_a(\omega)$ and $Z_s(\omega)$ are the mechanical impedance of the structure and PZT, respectively [5]. The equation shows that a change in the structure mechanical impedance is related to the electrical impedance of the PZT. ω means the frequency and a is the geometric constant of the PZT [5]. The rest variables ε_{33}^{T}, δ, d_{3x}^{2} and $\bar{Y}_{xx}^{E}$ represent the zero stress dielectric constant, dielectric loss tangent, piezoelectric coupling constant and complex Young's modulus of the PZT, respectively [5].

EMI based PZT has been studied for the application in various materials (e.g., metal pipes, composite materials, concrete etc.) and to improve the detectability of the damage in the materials. Despite of many studies, EMI suffers problems regarding the temperature, the type of damage and detecting damage location [10]. In this study, experimental studies were focused on the effect of the temperature on the prediction of the damage location of high strength cementitious composites with nano-SiO_2 [4].

PZT sensors are bound to be influenced by the temperature due to the nature of the PZT which is exposed to the external [4]. It is essential to offset the effect of the temperature to apply EMI based PZT in field. The temperature correction coefficient can be used to revise the impedance value to an ambient temperature [4]

Previous studies were conducted using neural network to predict the damage location [8]. In the present study, attempts to locate damage of composites were performed considering various temperature conditions and the result varied depending on the temperature [4]. Furthermore, improvement of the accuracy of predicting the damage area using the temperature correction coefficient was made [4].

2. EMI METHOD

Root Mean Square Deviation (RMSD), one of statistical methods, is used to quantify the acquired electrical impedance of the PZT. The RMSD equation is expressed by Eq. (2) [2].

$$\mathrm{RMSD} = (\textstyle\sum_{k=1}^{N}\left[Re(Z_k)_j - Re(Z_k)_i\right]^2 / \sum_{k=1}^{N}[Re(Z_k)_i]^2)^{1/2} \qquad (2)$$

Here, $(Z_k)_i$ and $(Z_k)_j$ are the reference impedance value of the PZT and the corresponding impedance value for each measurement at the k^{th} measurement point, respectively [2]. If the difference between the two impedance values is sufficiently large, a high RMSD value is obtained [9].

In this study, a commercialized AD5933 evaluation board was used for measuring impedance of all the experiments. The laptop installed software from Analog Devices modulated the frequency ranges and input voltage of the system.

3. NEURAL NETWORK MODEL

In this study, a back-propagation neural network model was adopted. A back-propagation neural network is one of artificial neural network functions [1]. The neural network embezzle multi layers consisting of input layers, hidden layers and output layers [1]. Adaptive weights of multi layers associate between input values and output values. Error value is minimized to update from the output layer to the input layer sequentially [1].

The utilization of neural network for the prediction of the output value by using the input value requires the minimization of the error value in each layer [1]. In this study, the input value and output value represent RMSD of each measurement and damage location, respectively [4]. Output values have a range between 0 and 1, and the output value of 0 means that there is no damage, while that of 1 means damage has potentially occurred [4].

4. EXPERIMENTAL SETUP

4.1 Change in impedance due to various temperature

To determine the temperature correction coefficient α, a single plate of high strength cementitious composites with nano-SiO_2 was prepared with three PZT patches attached near both ends and center of the plate with the application of the damage enhancement technique using a metallic layer [4, 7].

The prepared specimens were placed in a chamber to increase or decrease the temperature [4]. The temperature was varied from 20 ^{o}C to 60 ^{o}C and 20 ^{o}C to -20 ^{o}C with a step size of 1 ^{o}C per hour to obtain the impedance values with temperature changes. The frequency ranges were divided for shifts in the impedance constantly. The temperature correction coefficients with the frequency ranges were obtained by comparing the impedance values at various temperatures with that at an ambient temperature 20 ^{o}C [4]. The temperature correction coefficient $\alpha(f)$ was calculated by linear regression analysis with the average of impedance values and temperature.

The modified impedance value can be determined by $\alpha(f)$. The modified impedance value will be effective upon the assumption that the peaks in the impedance signature shifts in the identical direction subjected to temperature variations. Thus it becomes vital for one to choose a suitable frequency range for this study. Details of the temperature correction coefficient and modified impedance value can be found in Kim et al (2016).

4.2 Predicting the damage location using neural network model

In the experiment, three plates of high strength cementitious composites with nano-SiO_2 were fabricated and four PZT patches were attached onto each of the plates to enhance the damage detection capacity [4].

Each composite plate was divided into nine sections and the four PZT patches were attached to the four corner sections [4]. Three holes were made at each section, so 27 holes were made in total. The impedances of the PZT were measured at every hole [4]. Three plates were experimented at each of the three different temperatures [4]. The impedance results from both ends temperature were modified by using the temperature correction coefficient $\alpha(\mathrm{f})$ to ambient temperature to obtain modified RMSD values [4]. The accuracy of predicting the damage location by neural network using the modified RMSD values were compared with that of ambient temperature [4]. Details of the results of the experiment can be found in Kim et al (2016).

5. SUMMARY

1) In this paper, the effect of temperature on the prediction of the damage location was investigated. The temperature correction coefficient was obtained by comparing the impedance values at various temperatures with that at an ambient temperature.
2) Improvement of the accuracy of predicting the damage area using the temperature correction coefficient was conducted
3) Details of the accuracy of the predicting the damage location of high strength cementitious composites with nano-SiO_2 by application the coefficient will be further discussed [4].

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