Study the effect of nano vibration amplitude on the electromagnetic interaction of CMC structure

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Abstract

Vibration is a source of energy that can be beneficial or harmful based on the application. Vibration can affect the function of any structure; however, Ceramic matrix composite (CMC) is one of these structures. Whereby less studies have been concentrated on study its function specially when electromagnetic wave (microwave) exposed on its surface to perform its designed function. To address this concept, SiC composite has been fabricated which is designed to have a transparent characteristics to microwave. External vibration had been applied on its surface to monitor how much influence could nanoscale amplitude vibration damage the microwave interaction. The source of vibration was applied from piezoelectric and the vibration was monitored via laser doppler vibrometer, while the microwave band was generated from the network analyzer at a range of 8.2 to 12.4 GHz. The results revealed that vibration can assist significantly microwave penetration inside the composite and increase the transparent characteristic of the composite. This considers important for portable ceramic composite designed to interact with electromagnetic wave (radar) which covered with such structure.

Keywords: vibration of CMC composites, electromagnetic interfere with CMC, network analyzer.

1. Introduction

Ceramic matrix composites (CMC) have been employed intensively recently in various applications due to its unique properties (Tomar, 2013). The designed ceramic composites are oriented based on the function that required to performed (Qin and Brosseau, 2012). For example, in medical application, ceramic composite should fulfill biocompatibility and assist biofunction of human body (Ikumapayi et al., 2023, Słota et al., 2021). In industry, ceramic has to have robust and durability with a suitable mechanical property. Harsh environment such as high temperature that exceed 1000°C have been studied and analyzed recently specially for military and space industry (Ikesue and Aung, 2022, Dhanasekar et al., 2022, Steyer, 2013, Karadimas and Salonitis, 2023). Therefore, design a composite that able to withstand these characteristics with a good mechanical properties is an important criterion to enrich this sector (Schuldies and Nageswaran, 2010). Most of the recent ceramic composite designed to work with electromagnetic environment that involve a wide range of frequency band. However, the composite should possess a good interfere with these frequences by either absorb, shield or either transfer the aforementioned waves (Gao et al., 2018, Wei et al., 2018).

Vibration that generated due to working condition should not affect the main function of the designed composite. This property led to massive problem specially when the ceramic composite interferes with electromagnetic wave (Li, 2022).

Silicon carbide composite SiC is one the most materials that has a good thermal and mechanical properties due to its robust microstructure characteristics (An et al., 2021). SiC is a ceramic material posses' different property when joint with other materials in terms of electromagnetic interference properties, or when its particle size be in nanoscale (Huang et al., 2024). It is well known that SiC is a dielectric material and by its nature considered as a good reflector when expose to electromagnetic wave or in another word (microwave) (Li et al., 2022, Yu et al., 2023, Han and Luo, 2018). Therefore, mixing SiC with other materials could tune the dielectric properties to be either absorber or transparent to microwave. Han et al, (Han and Luo, 2018) fabricated SiC composite for shielding properties by adding carbon nano tube as a filler to the SiC. Yu et al (Yu et al., 2023) prepared SiC composite to obtain absorption properties of the composite. The effect of the filler as mentioned previously working as an assisting aid as tune the interaction with the electromagnetic wave. Whereby, transparent characteristic could be attained to allow more electromagnetic to pass through as in the study of Ding et al (Ding et al., 2011). This study revealed a transparent property due to the effect of fillers on the SiC.

Study the vibration of SiC composite in nano scale is important to understand the effect of this un sense vibration amplitude on the microwave interference. In this study, analysis of the dielectric properties of SiC composite when nano vibration amplitude was performed to examine the reflection and transparent to electrometric wave properties of the composite in the microwave range.

2. Materials and method

The basic materials that have been used in the investigation was silicon carbide nano powder reinforced by two fillers, silicon and zinc oxide. These two materials have different electromagnetic properties that able to influence the dielectric properties of SiC. The fabrication process of the composite started with mixing the components of the composite and pressed under four ton force to have a circular shape, the final step was sintering at 1600°C, more detailed is mentioned in our previous published paper (Hussein et al., 2023). The furnace that used in the experiment was tube type, and nitrogen was used as an environment covering the sample.

Vibration measurement was performed using; OMS Laser Point LP01 Laser Doppler Vibrometer (LDV), data acquisition system, function generator, piezoelectric, power amplifier, and other devices mentioned in the next section.

2.1.Experimental procedure

Figure 1 shows illustration diagram of the whole setup for vibration measurement. Vibration was measured for the sintered sample that fabricated as a circular disc with thickness of 4 mm. the sample was freely fixed as shown in figure 2. One side of the composite sample was attached to a piezoelectric in order to obtain nano vibration amplitude. The other surface of the sample was freely attached to the microwave adaptor in which microwave frequency band from 8.2 – 12.4 GHz was exposed directly on the sample.

The setup was provided two functions at a time, measuring the nano vibration of the sample and measure the frequency response of the sample while vibrated. The Laser Doppler Vibrometer (LDV) sensing the vibration via laser light as shown in figure 2 and this device connected to the power amplifier, the power amplifier connected to the PC to save and record the measurements. A data acquisition was also connected to the power amplifier, this device has four channels as shown in figure 2. The vibration source is applied form piezoelectric that get its signals from the function generator as mentioned in figure 1.

On the other hand, and as mentioned earlier the second surface of the sample was freely connected to the microwave adapter, whereby the signal was received via co-axial cable form the network analyzer type ENA 5071C. The method utilized in this investigation is a transmission line theory, the data obtained were analyzed and displayed in N1500 material measurement suite software.

The piezoelectric is a device that able to transform the electric signals into mechanical stress and vice versa. However, the function generator is connected to the piezoelectric to provide it with a range of signals. The first step of testing is running the LDV and do the calibration process, the calibration was begun with adjusting the stand and the LDV to be perfectly horizontal, then in the software a calibration bottom was clicked to ensure a reliable data obtain. Afterword, generating electric signal to the piezoelectric from the function generator. The final step is exposing the sample to the microwave band from the network analyzer. The data recorder at different frequencies to study their effect on the electromagnetic interaction of the SiC composite in terms of dielectric properties.

All devices mentioned previously work together at the same time in which they started from running the LDV followed by function generator that generate electric signal to the piezoelectric. When all devices started the network analyzer activated to generate the microwave spectrum. The measurement was focused on how much can nano vibration influence the interaction of microwave inside the sample and how could the dielectric properties be influenced.

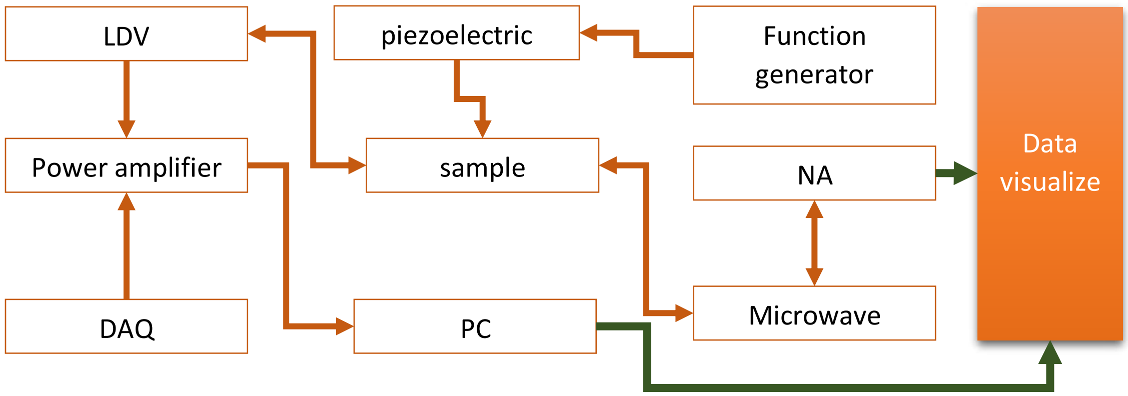


Figure 1: The whole setup for vibration measurement

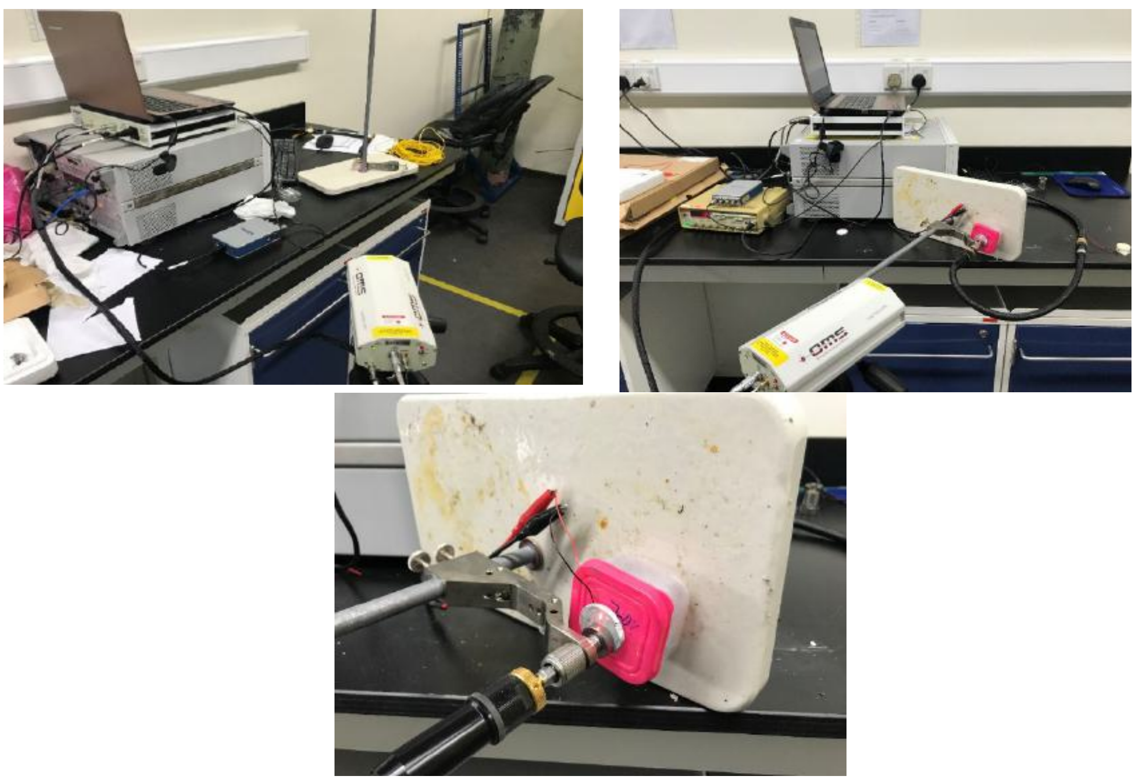
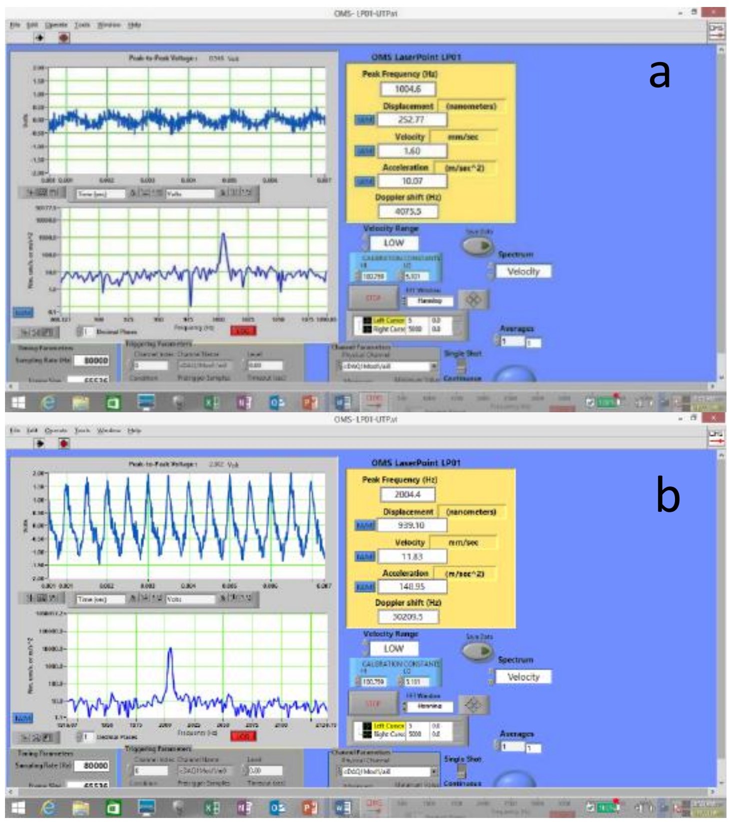


Figure 2: Microwave and LDV setup

3. Results and discussions

3.1. Vibration measurement

Figure 3 a-d shows the value of vibration amplitudes of the SiC composite. As can be seen that different values of peak frequency were obtained as long as changing the excited voltage of the piezoelectric. The test was perfromed online with the stress that generated from the piezoelectric. The value of peake frequency which represents the natural frequency of the composite varies based on the value of electric voltage applied to the piezoelectric to start at (1004, 2004.4, 3009 and 4002.7) Hz. However, this peak frequency associated with amplitude which is measured to be in nanoscale that ranging from 83.46 to 939.1 nanameter. This tiny value of amplitude shown the high response of the composite to any external excitation. However, the nano amplitude related to the high bond of the cpmposite due to many factors such as the nature of the ceramic materials that having a covelant bond which revealed a high strength with less flexibility. The other factor is the fabrication temperature of the composite that bond the component of the composite together in which reduced the porosity between them and made the transportation of any wave to be very small. It is worthy noted that when the excitement from the piezolectric changes, the value of the amplitude flactuated from high value to low value when ever the external excitation ncrease. This is resulted from the component of the composite that dramatically made the flactuation looks like a sine wave. The value of peak frequency started at 1004.6



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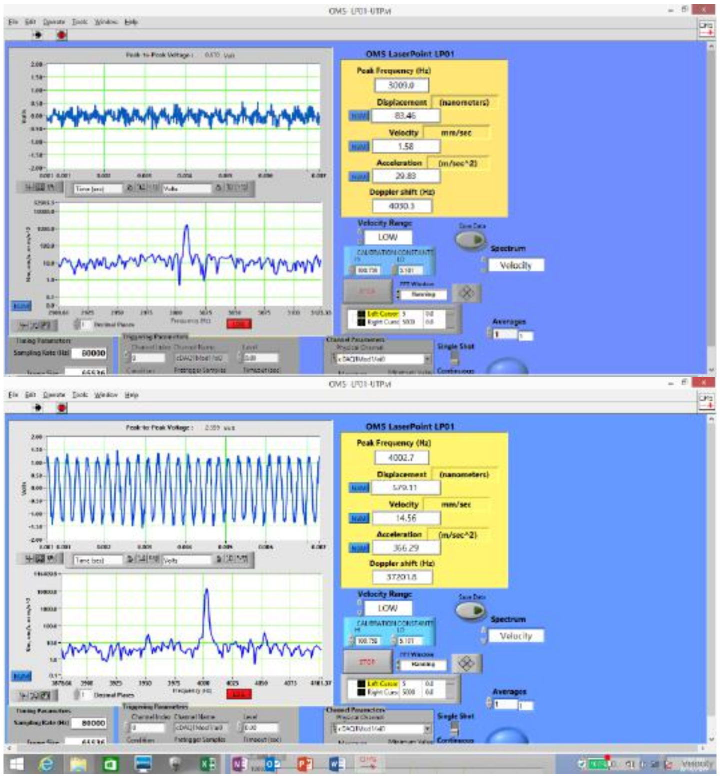

Figure 3: LDV results from the OMS software a) 1004.6 Hz, b) 2004.4 Hz, c) 3009 Hz, d) 4002.7 Hz

3.2.Microwave test

The microwave test was revealed a substantial effect of the vibration on the behavior of composite when expose to microwave. As can be seen in figure 4a, the dielectric properties of SiC composite (real part permittivity) shows a frequency response composite. Whereby, the response change along the frequency band to be maximum at the lower frequency and reduced gradually as long as the exposed frequency increase. The first test was examining the sample without any piezoelectric attached to the sample and the result was close to what was found in our previous published paper and literature (Hussein et al., 2023, Yin et al., 2014). The free sample exhibited a transparent behavior, whereby, the value of permittivity is less than 5 and it's reduced as long as the frequency band increase. However, any permittivity recorder less than the aforementioned value considered has less reflection or absorbing properties. On the other hand, when piezoelectric was attached to the sample, the value of dielectric has a little increase but still less than 5 to be around 3.83 at 10 GHz. This tiny increment related to the piezoelectric itself that occupy the center of the sample only, so its increase the amount of reflection due to its metallic nature.

Vibration is a source of energy that can has divers effect on any structure, it could be beneficial or cause catastrophic effect. When vibration applied to a hot liquid, it assists to increase heat transfer between the hot surface and the surrounding by accelerate the molecule motion and increase thermal loss. This concept can be said when electromagnetic field attain instead of heat, the vibration has a significant effect on the microwave propagation inside the composite structure. SiC composite is a multi-phase composite due to its components, thereby, these phases influence the overall wave interference. When vibration applied the interaction increased to allow more wave to penetrate inside the composite and help microwave to pass through due to the amplitude that reduce the scattering between the molecules. This reduction can be said like pores or gaps occur due to the nano amplitude. On the other hand, matching between the increase of the external excitation that behaved as a sine wave response of the composite as mention previously and the response of the composite when expose to microwave. All excitation from piezoelectric which has been starts from 1000 to 4000 Hz illustrate similar trend with no significant difference between the response of them along the frequency band. So, it can be said vibration has no negative influence on the transparency of the composite neither increase absorption or shielding the microwave. Figure 4 b shows the imaginary value permittivity of the composite. As can be seen that the values are very small close to zero except for the free sample that shows a tiny increment at 9.6 GHz and this is related to the component response, but when piezoelectric attached the response has reduced and then extra reduction has been noticed when vibration applied. All the results revealed that vibration increase transparent to microwave.

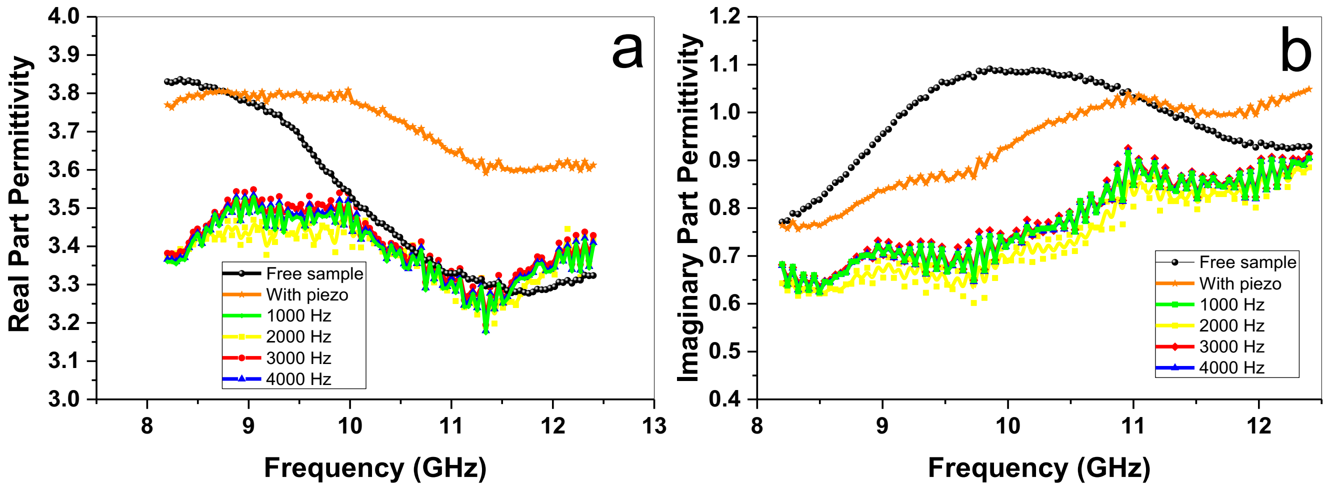

Figure 4: a) real part permittivity, b) imaginary part permittivity

4. Conclusion

In this study, vibration in nano scale was applied and monitored on ceramic matrix composite (CMC) based SiC. The vibration applied from piezoelectric and attached directly on the composite surface. The microwave band was generated from the network analyzer and measured how much was can be influenced by vibration. It is found that vibration has a positive effect on the transparent characteristics of the SiC composite. The increment was noticed from the dielectric properties of the composite, whereby, low vale permittivity less than 5 the composite said to have a transparent characteristic. This reduction in dielectric properties due to vibration amplitude that reduce the scattering between the molecules. This reduction can be said like pores or gaps occur due to the nano amplitude. However, vibration has no negative effect on a structure that allow microwave to pass through its structure.

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Conflict of Interest

There is no Conflict of Interest.

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