

## Article

# Investigating Electromagnetic Shielding Properties of Building Materials Doped with Carbon Nanomaterials

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**Abstract:** Electromagnetic (EM) shielding has become an essential element in the modern world alongside the increased use of electronic products and telecommunication equipment. We are surrounded by electromagnetic fields that have inevitably become formidable in our lives. It is possible to absorb EM waves by adding materials. Researches have focused the addition of different additives into the cement based mixture to increase the Electromagnetic (EM) shielding. This study aims to investigate the performance of carbon nanomaterial on mechanical, electromagnetic shielding properties of composite. Hence, samples were produced using obtained cement composites. After 28 days of curing, ultrasonic pulse velocity, flexural and compressive strength, water absorption tests and electromagnetic shielding were implemented for samples. As a result of this research, it was concluded that electromagnetic shielding was formed as the percentage carbon nanotube contribution increased, and electromagnetic pollution was partially prevented.

**Keywords:** electromagnetic pollution; mortar; nanomaterial



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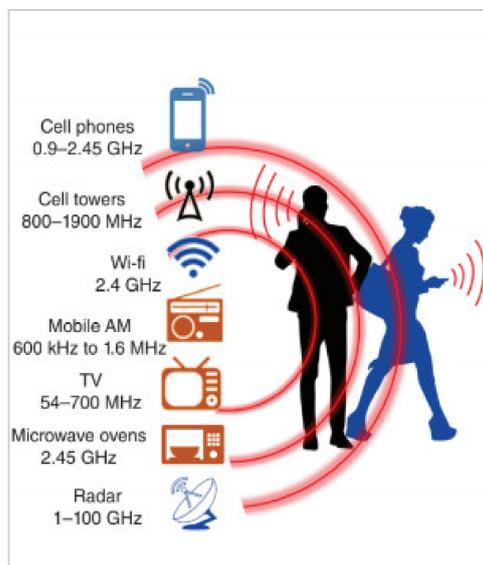
## 1. Introduction

Electromagnetism has become a large problem as a consequence of the continuous updating of electronic products and telecommunication equipment. We are surrounded by electromagnetic fields that have inevitably become a formidable force in our lives [1]. These fields were considered too weak to affect humans [2]. Electrical and electronic devices, which are used every day, generate electromagnetic radiation. Radio stations, television antennas, mobile electronic devices, microwave ovens, etc., have high frequencies [3]. Figure 1 shows EM sources. Although it does not seem possible to remove the technology from our daily routines, it is possible to prevent the effects of EM waves [4]. Proper electromagnetic shielding protection would not only ensure good working but also minimize radiative damage for the human body. In order to reflect the EM waves and prevent them from penetrating living areas, many shielding materials have been developed [5,6]. It is possible to absorb EM waves by adding materials [7].

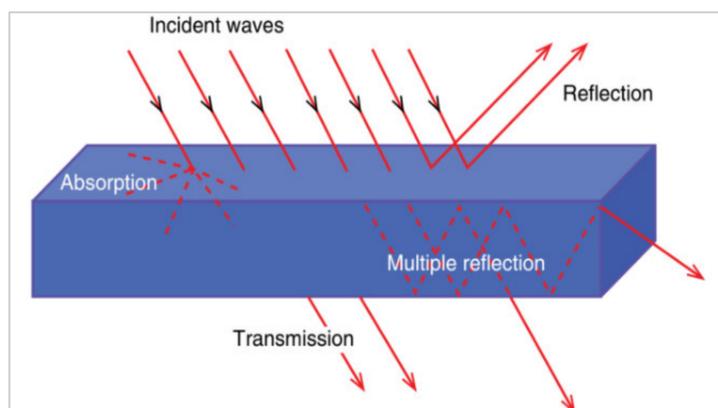
Understanding electromagnetic shielding mechanisms is important, guiding the significance of shielding materials' development. EM shielding is the process of lowering the electromagnetic field, blocking the field with barriers made of conductive materials [8]. Shielding is the sum of absorption and reflection loss and multiple reflections [9,10]. To be a shield against the EM, material should reflect or absorb the wave [11]. The mechanism of electromagnetic shielding is shown in Figure 2.

The developments have prompted the need for EM shielding materials in the construction industry. Conventional cement-based composites, commonly used in construction engineering, have poor electromagnetic properties [12,13]. Therefore, it is necessary to control the electromagnetic radiation inside buildings, provide adequate protection [14]. The development of cement composites has focused on the introduction of additive materials into cement paste to improve electromagnetic properties [15,16]. Mortar is a kind of

cement-based materials, which is usually used for masonry and plastering. In places that are vulnerable to electromagnetism, shielding materials can be applied as a coating on wall surfaces [17].



**Figure 1.** EM sources and effects on humans.



**Figure 2.** Mechanism of electromagnetic shielding.

In more recent years, carbon-based nanomaterials emerged as the best fillers for EM shielding materials with the advantages of having electrical conductivity and thermal stability. Carbon nanotubes are a new type of material that possess extraordinary properties and propagate nanotechnology [18]. The use of carbon nanotube in composites can lead to improvements of materials [19–22]. The use of carbon nanotubes with a very low percentage makes the cost of material very attractive. It was found that in addition to reinforcement benefits, CNT could improve properties of material, increasing cementitious matrix [23].

This study aims to investigate the performance of carbon nanotube materials on mechanical, electromagnetic shielding and microstructural characteristics of cement composite. Carbon nanotube nanomaterial from mortar mixture varied from 0.25%, 0.5%, to 1%. After the 28th day, ultrasonic pulse velocity, flexural and compressive strength, water absorption tests and electromagnetic shielding were implemented samples.

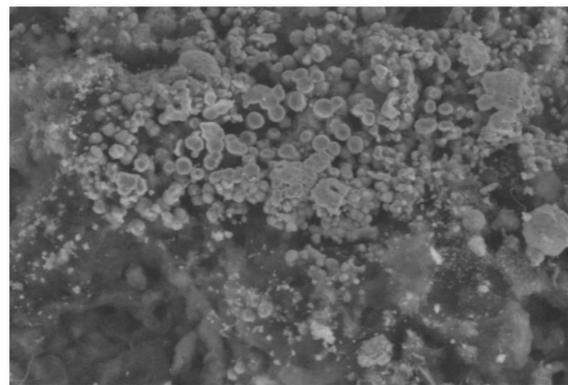
### 1.1. Materials

In this experiment Portland cement, standard sand, and carbon nanotube were employed. The properties along with carbon nanotube with 52 wt% iron oxide ( $\text{Fe}_3\text{O}_4$ )

(multi-walled carbon nanotube) nanoparticle (CNT) are included in Table 1 and a SEM picture is given in Figure 3.

**Table 1.** Properties of CNT.

Purity	99.9
Average Particle Size (nm)	30
Surface Area	45
Shape	near spherical
Color	black
Length ( $\mu\text{m}$ )	15–25
Specific Surface Area ( $\text{m}^2/\text{g}$ )	>65
Outside Diameter (nm)	>50
True Density ( $\text{g}/\text{cm}^3$ )	~2.4
Tap Density	0.15
Ash	<1.5
Electrical Conductivity	>98



**Figure 3.** SEM Picture of CNT.

The cement was CEM I 42.5 with a density of  $3.15 \text{ g}/\text{cm}^3$ . The cement's compositions are given in Table 2.

**Table 2.** Cement.

Component	CaO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	MgO	Fe <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	SO <sub>3</sub>	MnO	Cl	Loss of Ignition
Cement, %	63.90	4.81	16.80	1.94	3.55	1.24	0.74	3.02	0.12	0.01	0.44

The standard sand was produced by Limak. The grading of sand is given in Table 3. The sand density is  $2.563 \text{ kg}/\text{dm}^3$ .

**Table 3.** Grading of sand.

Sieve, mm	2	1.6	1	0.5	0.16	0.08
Percentage, %	0	$7 \pm 5$	$33 \pm 5$	$67 \pm 5$	$87 \pm 5$	$99 \pm 1$

### 1.2. Mixture

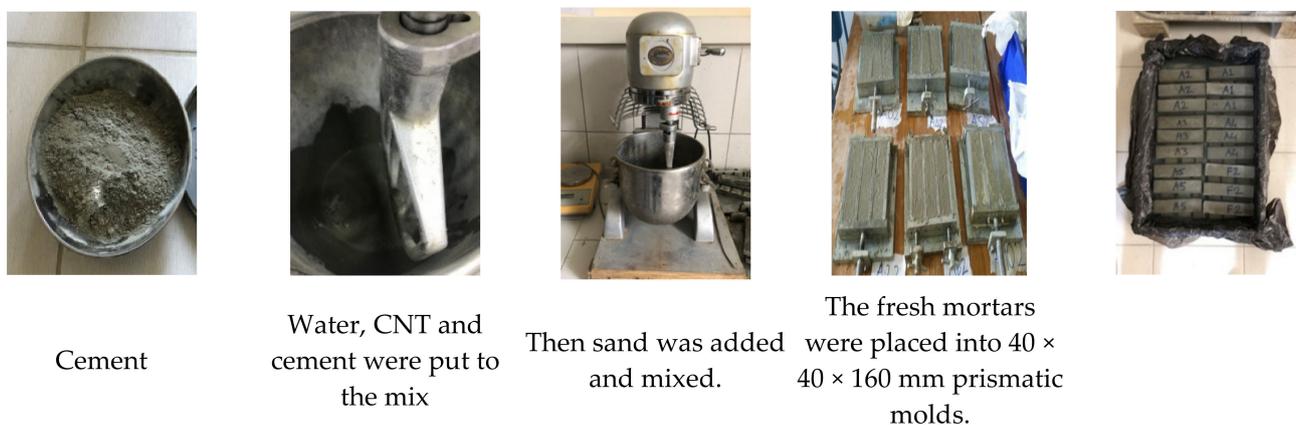
The nanomaterial CNT from the mixture was varied from 0.25%, 0.5%, to 1%. The mix proportion of mortar is seen in Table 4. Firstly, CNT were sonicated in water for 1 min.

Then cement was added, blended for 30 s. Sand was put mortar mixture. Mortars were placed into 40 × 40 × 160 mm molds. After 28 days of curing, compressive strength, water absorption, ultrasonic pulse velocity, flexural strength, the electromagnetic shielding of the samples was determined.

**Table 4.** Mixed proportions of composites.

No	CNT Ratio (%)	Cement (g)	CNT (g)	Sand (g)	Water (g)	Binder/Water (%)
NM0	0	450	0	1350	225	0.5
NM1	0.25	450	1.125	1350	225	0.5
NM2	0.5	450	2.25	1350	225	0.5
NM3	1	450	4.5	1350	225	0.5

The mortar preparation process is given in Figure 4.



Cement

Water, CNT and cement were put to the mix

Then sand was added and mixed.

The fresh mortars were placed into 40 × 40 × 160 mm prismatic molds.

**Figure 4.** Mortar preparation process.

### 1.3. Methods

The flexural and compressive tests were performed according to TS EN 196-1 [24]. Strengths were calculated using Equations (1) and (2), respectively:

$$R_f = (1.5 \times F_f \times \ell) / b^3 \quad (1)$$

$R_f$  is flexural strength,  $F_f$  applied load,  $b$  side of square of prism,  $\ell$  distance

$$R_c = F_c / 1600, \quad (2)$$

$R_c$  compressive strength,  $F_c$  maximum load, 1600 area

Water absorption tests were implemented for the samples. It was calculated according to Equation (3).

$$W_A = ((W_w - W_d) / W_d) \times 100, \quad (3)$$

$W_A$  water absorption,  $W_d$  dry weight,  $W_w$  weight of water immersion.

EM was measured according to ASTM 4935 using a ROHDE&SCHWARZ network analyzer. The experiment is shown in Figure 5, containing two antennas.

SEM analyses were made in NABILTEM, by using an FEI Quanta FEG 250 microscope.



Figure 5. EM measurement system.

## 2. Results

Most of the results reflected an improvement in strength, by adding or replacing cement in a small dosage of nanomaterials. The influence of incorporating CNT on compressive, flexural strengths of composites are given in Figures 6 and 7.

Flexural strengths were in 5.03–5.77 MPa. The specimen NM1 showed similar strength in NM0. The results prove that flexural strength is almost close with that of the MN0, except MN3.

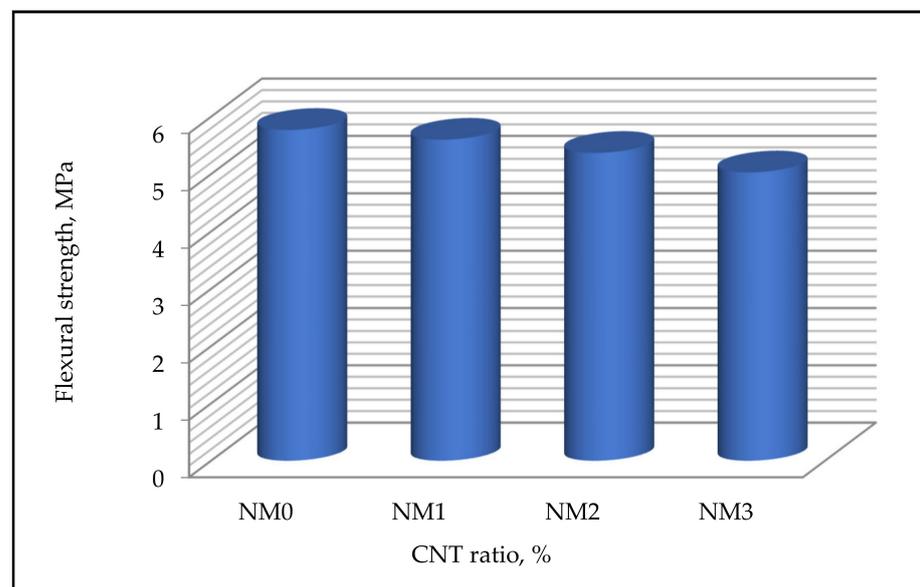
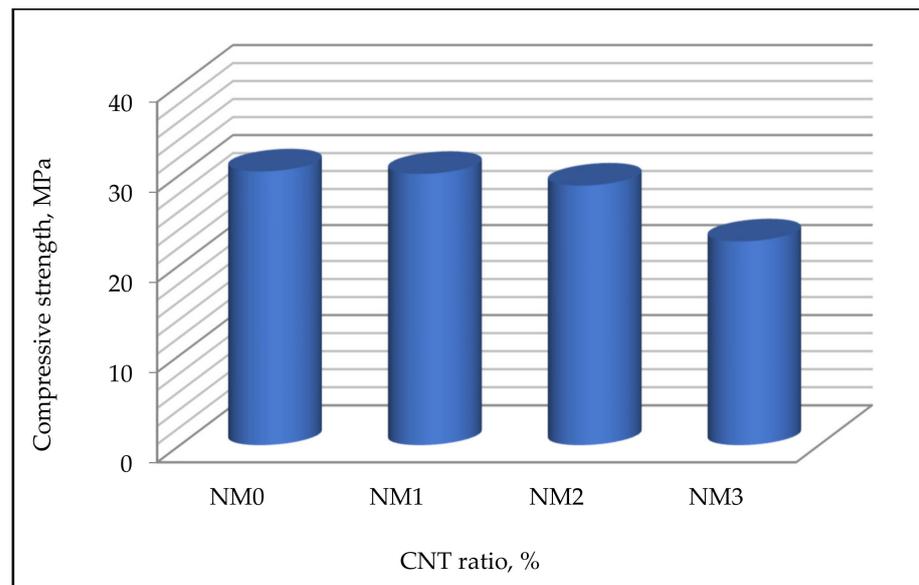
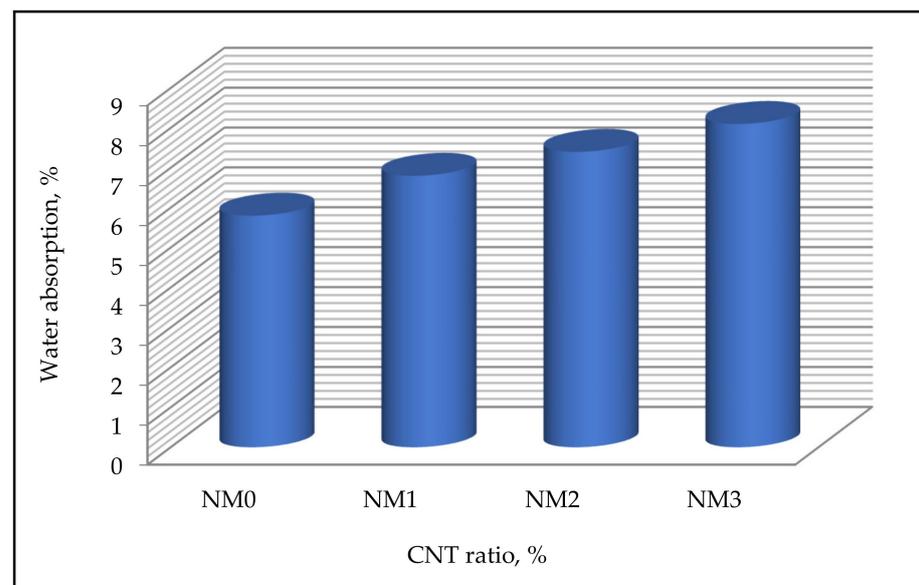


Figure 6. Flexural strength.

The compressive strength of mixtures at 28 day of curing are shown in Figure 8. Strength results NM0 and NM1 mixtures are consistently lower than NM2 and NM3 mixtures. The strength results of NM2 and NM3 were lower than mixtures NM0 and NM1. Particularly, when the amount of CNT increased, the strengths decreased because CNT is a hydrophobic composite. Water absorption percentages of mortars is shown in Figure 8.



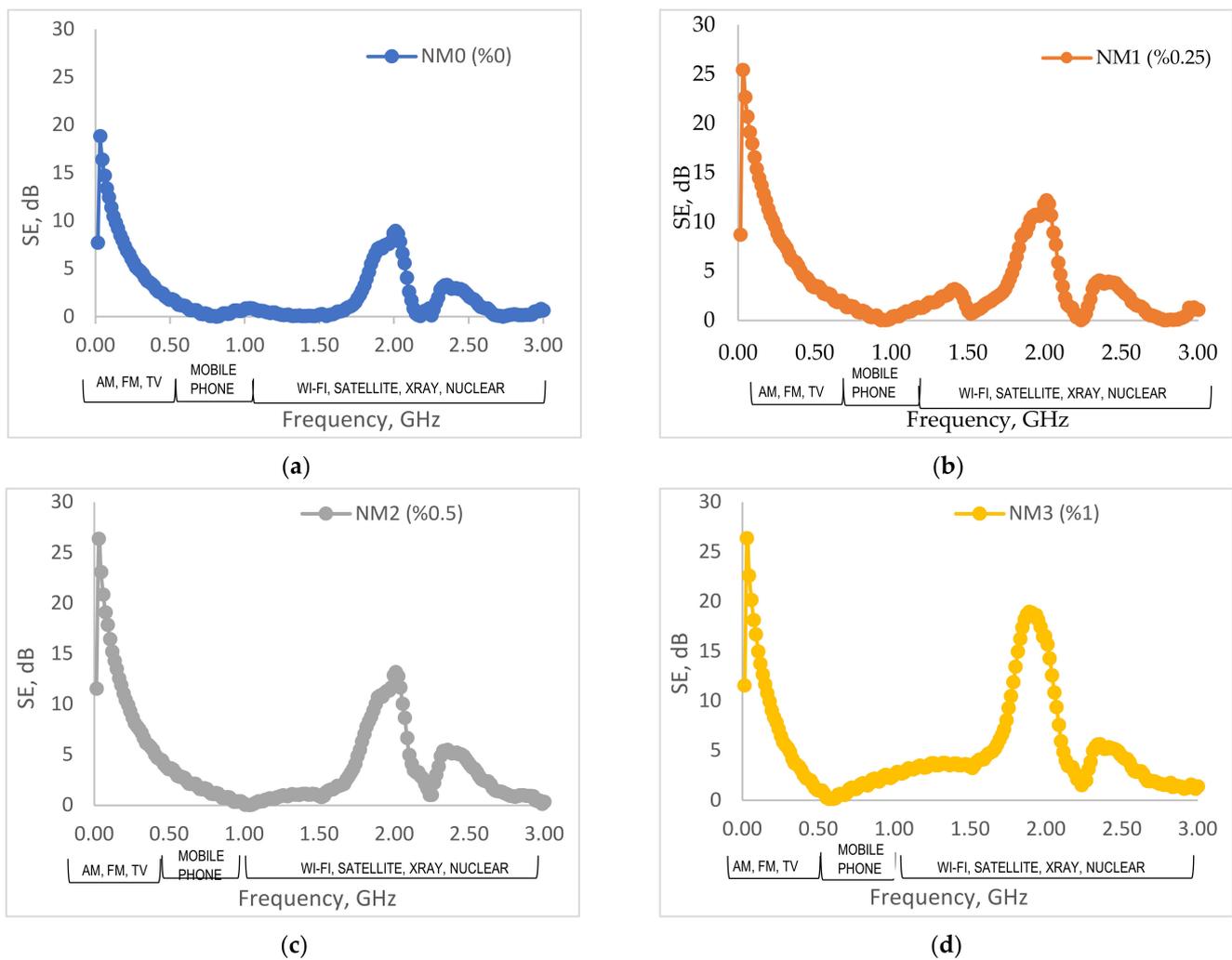
**Figure 7.** Compressive strength.



**Figure 8.** Water absorption.

Figure 8 shows that NM0 had the highest water absorption compares to NM1, NM2, NM3. Water absorption values increases significantly with the NM0. When the results were compared to NM0, the effect of the amount of the CNT on the water absorption of the mixture was negative.

Electromagnetic tests were carried out within 0 GHz to 3 GHz. The maximum EM shielding was obtained at a frequency of 2 GHz, when the CNT was 1%. Addition of CNT into the cementitious matrix increased the EM of the composite. The addition of CNT into cementitious material has shown a significant increase in NM3. All mortars had peaks at 2 and 2.40 GHz (Figure 9). The SE was the highest at about 2 GHz for all specimens. The mortars had the highest EMI shielding effect at a frequency of 2 GHz and 2.5 GHz. The incorporation of CNT nanomaterial into the mixture led to an improved EM. In Figure 9a, it was confirmed by comparing NM0, and the shielding effectiveness of NM3 improved compared to NM0 (Figure 10). The CNT improved the shielding effectiveness, owing to the carbon content in the CNT.

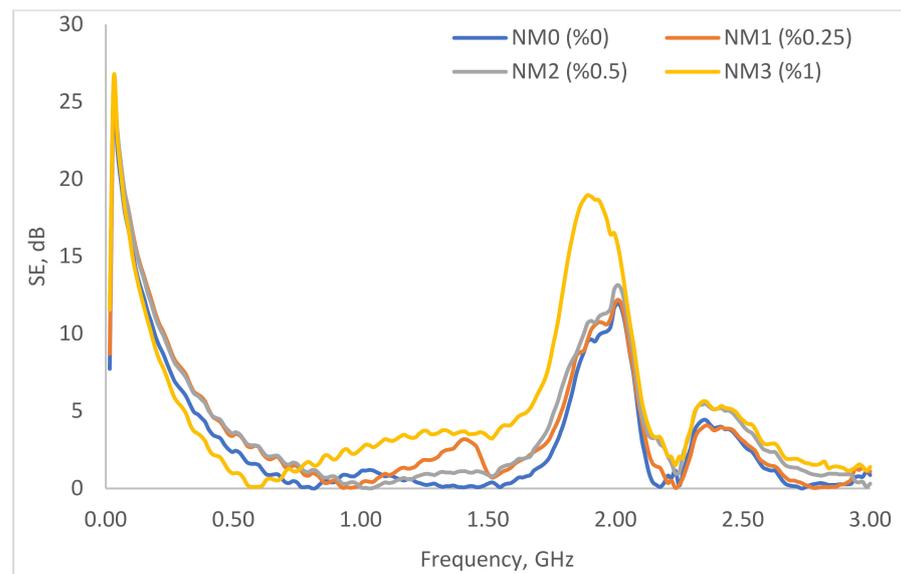


**Figure 9.** Electromagnetic (EM). (a) Reference composite; (b) NM1 composite; (c) NM2 composite; (d) NM3 composite.

Electromagnetic shielding represents a way toward the improvement of the electromagnetic compatibility performance. Carbon was added to cement at a different ratio of the mortar but considerably improved the shielding performance, especially at frequencies above 1 GHz. Moreover, the inclusion of CNT has been shown to be against EM waves. EM shielding materials are those that absorb and/or reflect EM radiation. EM waves are extensively used in different fields such as medical, wireless, communication, etc., where EM shielding is a prime requirement.

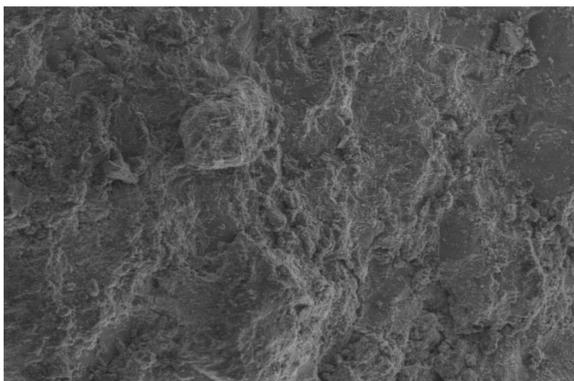
The capability of material to shield an EM can be expressed in terms of EM shielding effectiveness (SE), which indicates the level of incident signal that is blocked by shielding material. An SE of 20 dB means that 99% of incident signal power is blocked, as required for communication [25].

In SEM analysis, detailed effects of nanomaterials on the mechanical properties of mortars are discussed from a microstructure perspective. Most researchers reported that the increase in strength with very small dosages of nanomaterials owed to the role these finer particles. These particles provide further nucleation sites for a pozzolanic reaction, which generated additional C-S-H, thus leading to an increase in strength. Other researchers attributed the increase in strength due to improvement in interfacial transition zones (ITZ). The addition of nanomaterials prevents large pores to create and consume  $\text{Ca}(\text{OH})_2$  formed in ITZ.

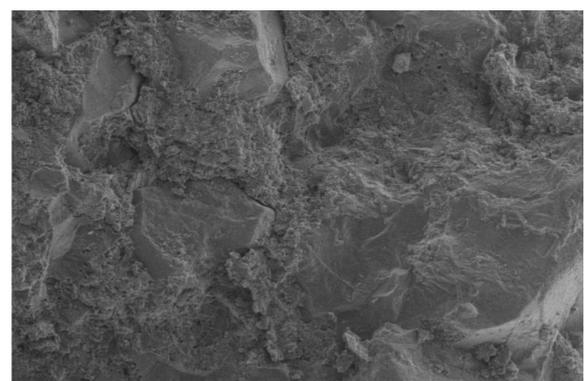


**Figure 10.** Electromagnetic (EM).

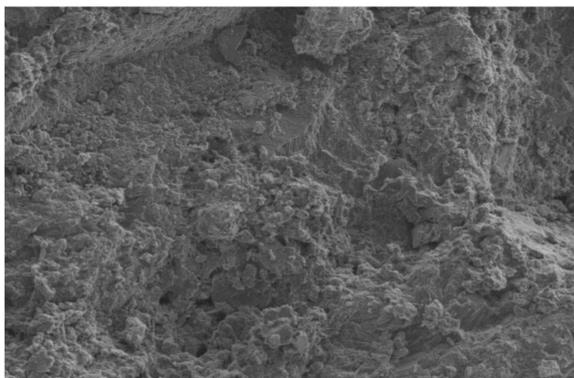
Figure 11 shows the homogeneous distribution of mixtures. Figure 11b–d CNT have been distinguished because the nanotubes are homogeneous.



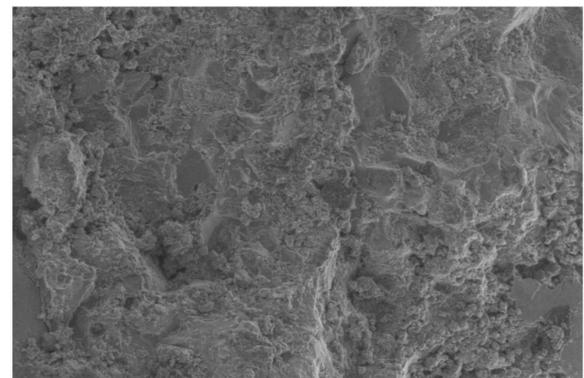
(a)



(b)



(c)



(d)

**Figure 11.** SEM. (a) Reference composite, (b) NM1 composite, (c) NM2 composite, (d) NM3 composite.

### 3. Conclusions

This research presented the impact of using CNT on the properties of mortar structures. Conclusions were obtained from the overall test results.

Flexural strength was in the range of 5.03–5.77 MPa. The specimen NM1 showed similar strength to NM0. The results prove that flexural strength results are almost close with those of the NM0 except MN3.

CNT reinforced mortar has already proven its improved mechanical properties in terms of strength. CNT is more effective in filling the nano pore space, and as a result, mechanical properties are enhanced. When results were compared to NM0, the effect of the amount of the CNT on the water absorption of the mixture was negative.

Electromagnetic tests were carried out within 0 GHz to 3 GHz. The maximum EM shielding was obtained at a frequency of 2 GHz, when the CNT was 1%. Addition of CNT into the cementitious matrix was increased in the EM of the composite.

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