

Nano-additives and their effects on the microwave absorptions and mechanical properties of the composite materials

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Abstract. The review addresses the effect of various carbon and iron-based percentage nano-additives on both electromagnetic (EM) wave and mechanical properties of composite materials. It also assessed the influence of particle and fiber size along with the manufacturing process, on mechanical properties (tensile strength and flexural strength), fracture behaviors (fracture toughness) and electromagnetic properties (reflection loss). Reviewing the selection of nanomaterials for a particular frequency band and application, as well as their impacts on bulk materials in relation to loading, were overviewed. As per this review, adding those iron and carbon-based additives influence positively for both electromagnetic and mechanical properties. Furthermore, review organized natural based fiber and filler-based composites along with fillers for the production of green strong radar materials. The review also showed, how highest and smaller percentage of iron-based fillers affected for microwave absorption and mechanical properties. Mainly, the optimized use of nano particles percentage for both mechanical and electromagnetic wave to produce strong radar materials were overlooked. Finally, these papers give a quick hint on how these nano particles manufacturing methods and particle size affect the mechanical properties and micro wave absorption of composite materials.

Keywords: Microwave absorption / iron powder / nano carbon / tensile strength / fracture toughness / nanocomposite

1 Introduction

Microwave absorbing materials (MAMs), mostly called radar absorbing materials, are opening the way and new technology advancement for interesting applications in Electromagnetic (EM) wave pollution prevention and defense security. Because these materials provide an advanced alternative to traditional reflection principles for essentially eliminating EM radiation [1]. However challenges occurred to design the microwave absorbing materials one of the challenges for both academia and industry is to develop wideband microwave absorbing and shielding (MA&S) structures that are economical, light-weight, strong, and have unusual electromagnetic and mechanical properties [2]. Stealthy aircraft are less observable (or ideally unseen) to the detection devices like; radar, acoustic sensors, laser, infrared (IR) or near infra-red (NIR) [3]. Mainly stealthy vehicles are made of radar absorbing materials (RAM) in parts of it and the proper handling of shapes in designing, the hull and

superstructure [4], which mainly allows significant reduction in the amount of energy reflected to enemy radars [5]. Likewise most stealth ships are designed by geometry or shaping and painting, due to some complexity only a few stealthy ships are constructed by applying RAM stealthy technique [6].

The applications of RAM in different sectors of aerospace and aeronautics (particularly aircraft and spacecraft) can be expressed by their durability, high strength, mobility, and radar invisibility. Those materials are also used in nuclear physics, which is for protection from nuclear EM pulses (NEMP), and shields in particle accelerators. RAMs are also used in the mitigation of human exposure to direct or indirect protection approaches against various EM signals (EM sources), electronic device development, from mobile phones to radios, which affect human and animal life. There for EM, signal shielding is critical for protecting vehicles, electronic devices and human health [7,8].

Dielectric and magnetic EM absorbers are the two most common types of EM absorbers. Most EM wave absorption materials are made by mechanical mixing of these materials [9]. Iron, Nickel, Cobalt, Gadolinium, some

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types of steel (e.g., ferritic stainless steel), boron alloy (Nd magnet) are the most magnetic metals and ceramics, plastic, mica, dielectric glass-ceramics and carbon-based materials are di electric material [10,11]. To enhance the dielectric and magnetic absorbing materials, different nano modifiers, can be used. Carbon nanotube (CNTs, MWCNT) [12–15], carbon black [16,17], activated carbon derived from coconut-fiber [18], carbonyl-iron nano particles [19–22], iron oxide nanoparticle [23], (Fe, Co) oxide nanoparticles [24], Fe_2O_3 and SiC particle [25], Ni-Zn ferrite [26], copper nanoparticles [27], NiO [28] are some of additives mostly applied for electromagnetic wave absorption. MWCNT [29,30], iron powder [31] are some particles used for mechanical and fracture behavior enhancement.

The main objective of this review is to compile the influence of nano particles on both mechanical and electromagnetic properties of composites for strong radar materials. Loading of these nano particles are critical and identifying the appropriate concentration is challenging. Some nano loading may be good for electromagnetic properties however, not for mechanical properties, and some loadings are good for both. This review mainly assesses the optimal concentrations of nano loadings for both electromagnetic and mechanical property increments of composites. Furthermore, the manufacturing method, wt% size and shape of carbon nano particle, and iron powder loading will be addressed for both mechanical and electromagnetic properties.

2 Effect of carbon, iron-based additives and green materials on microwave absorption

2.1 Effect of carbon-based additives on micro wave absorption

Carbon-matrix composite containing continuous carbon fibers was discovered to be a good EMI shielding material due to high dielectric properties. Carbon has attractive electrical properties due to its semiconductor properties since it allows a little amount of charge to pass through it [32]. The current state of research on various carbon nanomaterials, including 0D nanocarbon having spherical shapes, 1D carbon nanotubes, 2D carbon platelets, and 3D porous carbons, with their composites like ceramics, magnetic materials, metal sulfides, and conductive polymer is still undergoing research to get excellent electrical and mechanical properties [33]. The most known carbon-based materials used for electromagnetic wave absorption are nano carbon, carbon-filled polymers, hybrid composites, carbon or graphene scaffolds, and carbon nanotubes [34]. The wide spectrum of radar absorbing fillers are carbon-based materials, like carbon black, carbon fiber, single walled & MWCNTs, graphene, reduced graphene oxides, and so on [3].

According to the finding of Tang et al. [35] carbon black/reduced graphene oxide (CB/RGO) composites had higher absorption intensity and a wider effective absorption bandwidth, when compared to CB particles. The maximum absorption was as high as 47.5 dB with a modest filler content of 7 wt%, and the effective absorption

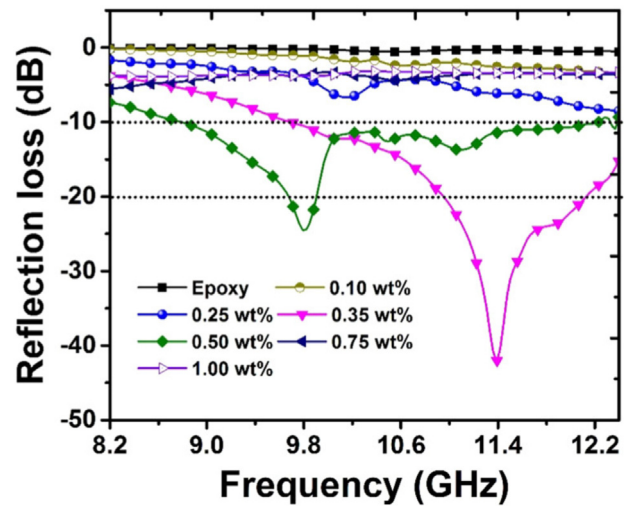


Fig. 1. Frequency-dependent reflection loss of CNTCF/epoxy composites at different filler concentrations at 2.5 mm thickness. Reprint with the permission from [37]. Copyright (2020) American Chemical Society.

bandwidth (reflection loss -10 dB) reaches 5.92 GHz, encompassing 37% of the whole measured bandwidth at a thickness of just 2.2 mm. Another researcher Ling et al. [36] did on the effect of CB on micro wave absorption of polymer. From the researchers result, the appropriate loadings from 0 to 10 wt%; 7 wt% of carbon black showed maximum reflection loss (RL) and achieves 24.02 dB (99.6% absorption) at 9.0 GHz with 2.75 mm thickness.

According to Figure 1, the RL intensity in these composites within the X band frequency domain initially rises to the maximum value and subsequently falls when more carbon nano tube carbon fibers (CNTCF) were added. The RLs, with 0.10, 0.25, 0.35, 0.50, 0.75, and 1.0 wt% CNTCF loading, reach 3.40 (54.29% absorption), -8.5 dB (85.87% absorption), -42.0 dB (99.99% absorption), -24.5 dB (99.65% absorption), 5.6 dB (72.46% absorption), and -3.8 dB (58.31% absorption) at 12.4, 12.4, 11.4, 9.8, 8.2, and 8 GHz respectively. At 11.4 GHz, 0.35 wt% CNTCF clearly showed the highest absorption (99.99% absorption) in the current condition.

Nano particle loading and thickness of the materials are factors on micro wave absorption of materials. For example, CNT films and silicone rubber (SR) plate composite showed better microwave absorption for small CNT loading (0.5%), with a minimum reflection loss (RLmin) of -26.55 dB for CNT films/SR composite [38]. Multi-walled carbon nanotubes (MWCNTs) and different ceramic particles were also used as absorbers in microwave absorbent composites and greatly increased the absorption produced by adding ceramic particles [39]. For stealth applications, wideband dielectric absorbers based on carbon fiber and carbon black powder were developed, prepared, and electromagnetically tested by Baskey et al. [40]. The result showed that, for 2 mm thickness, the minimum absorption capacity was 97% throughout the frequency range of the X-band. Another interesting

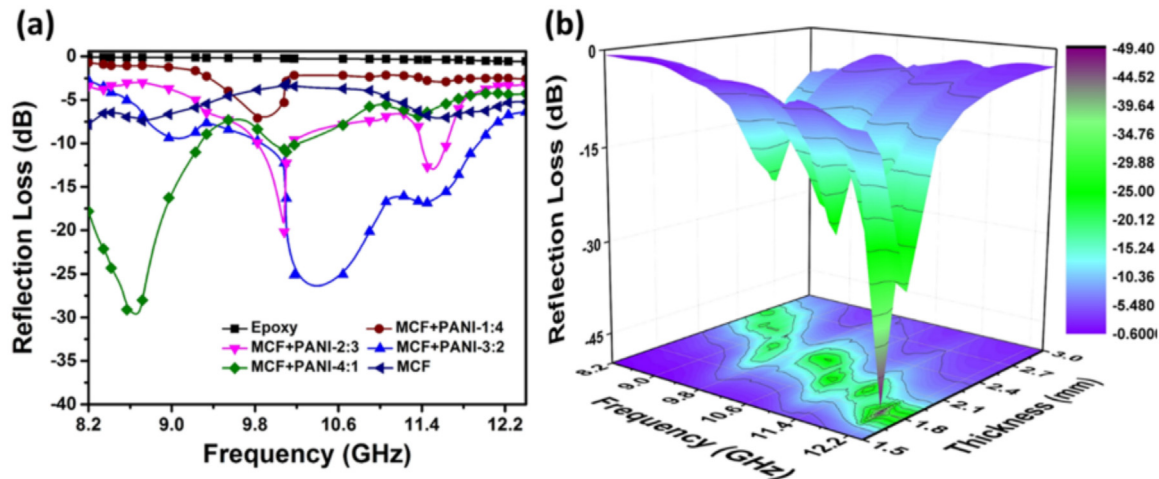


Fig. 2. RL curves of (a) MCF/epoxy and MCF/PANI/epoxy nanocomposites with a 2.5 mm thickness and (b) 3D RL of MCF + PANI-4:1 within the 8.0–12.0 GHz frequency range “Reprint with the permission from [42]. Copyright (2020) American Chemical Society.

research was done by Che et al. [41] on influence of three commercially available multi-walled CNTs, Baytubes C150P (Bayer Material-Science AG, Germany), Nanocyl NC7000 (Nanocyl S.A., Belgium) and MWCNT-VAST (VAST, Vietnam) (MWCNT) materials on the micro-wave absorption of epoxy composites and was made via ball-milling nanotube dispersion in the resin matrix. The highest microwave absorption was found in Nanocyl NC7000, which had a CNT content of only 0.25 wt% and the maximum reflection loss peak 18.4 dB was observed at 8.8 GHz and 16.5 dB at 10.3 GHz.

From Figure 2, the resonant absorption peak was significantly off-centered with respect to frequency, and the variation in PANI content greatly affects its amplitude. When compared to pure milled carbon fiber (MCF)/epoxy nanocomposites, the RL performances of MCF/PANI/epoxy nano composites were significantly improved. As the PANI concentration increased from MCF + PANI (1:0) to MCF + PANI (1:4), the RL value within the studied frequency range varied from -7.01 to -8.7 dB. PANI (1 wt%) + MCF (4 wt%) was found to have the greatest RL value of -29.8 dB at 8.6 GHz central frequency. For 1.1 GHz width band, 10 dB RL (more than 90% absorption) was also observed with 2.5 mm thickness.

Figure 3b illustrates the absorption characteristics of the composites (2.3 mm thickness) when the absorbent filler was swapped out for porous carbon fibers. The porous carbon fibers have outstanding microwave absorption properties, which are readily apparent. At 9.7 GHz, the composite with porous carbon fibers with 6 wt% and a thickness of 2.3 mm exhibits the lowest reflection loss which was -32 dB. With similar content of porous carbon fibers increase by 19.8 dB by varying the thickness to 3 mm. It is believed that the dielectric-type absorption and the interference of multi-reflected microwaves enhanced microwave absorption for porous carbon fibers [43].

To explore both mechanical and electromagnetic properties, a MWCNT modified polyaniline epoxy in glass fiber reinforced polymer laminates using the wet-layup vacuum bagging method was produced by Jelmy et al. [44].

Based on the result, MWCNT/PANI modified epoxy with 1.5 wt% and 2 wt% has the lowest reflection loss at 3 GHz. -16 dB was recorded for the laminate with 0.5 wt% MWCNT. Adding 2 wt% MWCNT also decrease the RL to -30.1 dB.

Carbon black (CB) was mixed into epoxy resin composites containing hardener, acetone, and resin acceptor to create wave-absorbing coatings by Mehdizadeh et al. [45] and the absorption bandwidth of the double-layer sample with CB ratio (7 wt% + 10 wt%) in each layer reaches -32.1 GHz.

According to Table 1, combining two nano additives (dielectric or magnetic) improves the composite materials' electromagnetic characteristics more than using only one. But it's also crucial to pick the right combination of these ingredients. For better absorption, the bulk material must also be properly taken into account. For instance, the MWCNT Nano additive displayed several characteristics, including variations in concentration.

Length of fibers, composite layout and size of nano additives affect the micro wave absorption properties of composite materials. For example, Breiss et al. [48] studied the effect of carbon fiber length on carbon fiber composites for microwave absorption. Short carbon fiber with 3 mm length showed losses for higher frequencies (about 15 GHz), however, long carbon fibers with 12 mm length showed the highest dielectric losses for low frequencies (below 4 GHz). In this study, 3 mm, 6 mm and 12 mm carbon fiber was used with 0.5% concentration. Assal et al. [49] also studied carbon fiber lengths which length from 1 mm to 12 mm with 3 mm range on dielectric properties. The research discovered that long fibers showed higher dielectric properties than short fibers that range lower than -50 dB for frequencies ranging between 8 GHz and 18 GHz. But this amazing dielectric property was obtained because of using pyramidal absorber and it had advantage of both material and shape of absorbers. The reason why these properties obtain was due to advantage of shape and nano particle used. Zhou et al. [50] also studied the effect of composite layout configuration on micro wave absorption of carbon

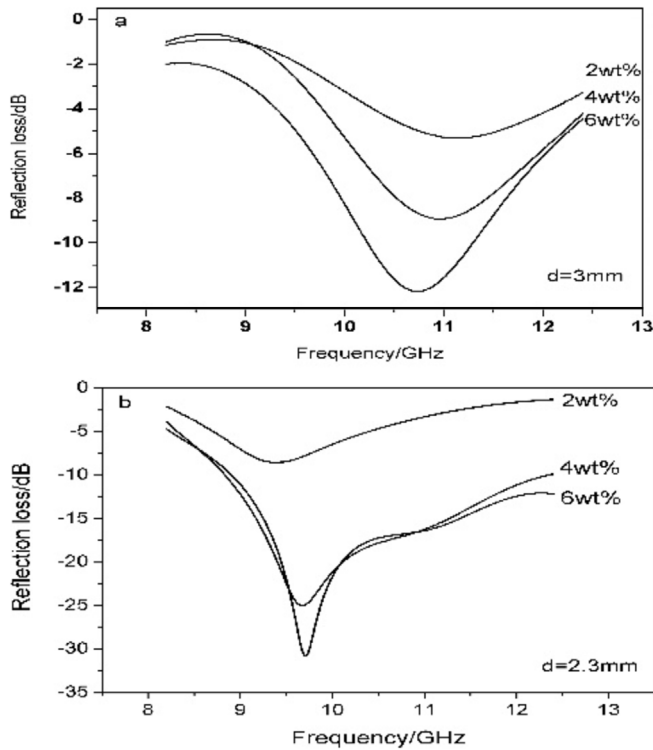


Fig. 3. Absorption properties of composites filled with carbon nanofibers with a thickness of 3 mm (a) and with porous carbon fibers with a thickness of 2.3 mm (b) Reprint with the permission from [43]. Copyright (2012) American Chemical Society.

fiber reinforced composites. The unidirectional CFRP laminate shifts from good conductor to lossy dielectric materials when the ply angle varies from 0° to 90° . The fiber orientation highly affects the microwave response of multidirectional CFRP laminates. The impedance of the laminate will be substantially lower than that of air if the parallel alignment is used in the head-most layer(s). The laminate consequently tends to reflect the microwave. The multidirectional CFRP laminate can be converted to microwave absorbers when the cross-ply is placed distant from the microwave-radiating surface. Singh et al. [51] did nano composites using CB nano particle and epoxy which has particle sizes of 15, 25, 55, and 65 nm. 25 nm particles showed significant EM absorption capability at 9.5 GHz. The effect of profile was also studied by Bizhani et al. [52] and the result showed, nano additive with triangular profile provided the lowest reflection over the widest bandwidth.

2.2 Effect of green carbon-based materials on microwave absorption

Natural based material used as filler or base material for electromagnetic wave absorption due to their high carbon content. Due to its high carbon content, charcoal improved microwave absorption of dried bananas as well as other agricultural byproducts like coconut byproducts, rice husk, sugarcane bagasse (SCB) and corn which are potential for microwave because of their, low density, easy availability, and green for environment. As corn charcoal has 83%

carbon content, it is the best with regard to microwave absorption performance and is promising for production of green radar material [53]. Simulation analysis which were done by Pattanayak et al. [54] showed, that the absorption rate can vary by varying the dimensions of the sample. The coconut fiber, coir and charcoal composites have a huge potential in serving as an alternative material in fabricating eco-friendly microwave absorbers. Different agricultural residues are assed for micro wave absorption techniques in [32] and a futuristic vision of these microwave-absorbing materials as a feasible alternative for serving as green microwave absorber. The reason behind this fact is due to high presence of carbon in these materials. Agricultural wastes are used to make pyramidal absorbers in a very efficient and effective way, with very few chemicals used. The performance of banana leaves has been substantially improved and used for microwave absorber, because of high carbon content material [53]. A single-layer microwave absorber based on rice husk Ash/CNT composites was investigated by Lee et al. [55], adding CNTs to rice husk ash (RHA) increased the minimum absorption from -8 dB to -15 dB for a bandwidth of 10.8 GHz to 12.8 GHz. Demands for lower energy consumption and lower environmental impact are pushing the development of natural fiber-reinforced composites (NFRCs) in a variety of industries. Natural fiber has various advantages over synthetic fiber, including biodegradability, low cost, light weight, superior life-cycle performance, along with satisfactory mechanical qualities [56]. The electromagnetic shielding properties are promising and need more investigation to commercialize as a shielding material. Some natural fiber composites were reported with their cellulose content ($(C_6H_{10}O_5)_n$); Kenaf with 53.14%, sisal with 68%, Cissus Quadrangularis Stem with 82.73%, jute fiber 72% and red banana with 72.9% [57]. The percentage of carbon directly affects the microwave absorption of natural fiber based composite materials.

Xia et al. [58] produced Hybrid composites of natural fiber mats, aluminum sheets, and epoxy resin using the closed-mold process. Micro wave absorption and mechanical properties were also tested. The samples were neat hemp fiber mats, hemp and aluminum sheet within, to see the effect of natural fibers in electromagnetic shielding. The presence of Al in the material increases the reflection and decreases absorption. Micro wave absorption in electromagnetic shielding increased when the natural fiber reinforced composite increased. Xia et al. [59] also applied Cu film magnetron sputtering in kenaf fiber composites for electromagnetic shielding function. After 0.5 h of treatment, the composite surface developed a coppery color and increased from 2.8 dB to 23.8 dB with 0.5 Hr Cu sputtering in Kenaf fiber composites, it is almost 99.5799% micro wave absorption. While adding the magnetron sputtering time from 0.5 h to 3 h, the specimen color didn't change significantly, however, the shielding increased from 23.8 dB to 48.3 dB. Another interesting research was done by Ding et al. [60] on electromagnetic shielding properties of kenaf fiber-based composites with various amounts of iron oxide impregnation for frequency range of 9–11 GHz. Ferric and ferrous ion solution was introduced by fiber

Table 1. Representative summary of the effect of carbon-based nano particles on electromagnetic absorption.

No.	Bulk material	Additive type	Loading wt. %	RL min. (dB)	Frequency range for RL < -10 dB	References
1	Polyester (PE) matrix	(MWCNTs)	3 wt%, — 5 wt%, — 10 wt% —	-15.8@10 GHz, -18@8.1 GHz -4@12.2 GHz	Whole X-band 8.20–10 GHz —	[46]
2	Polymer composite	3-types of MWCNT	2.0%wtMWCNT vast Baytubes C150P — 0.25wt%Nanocyl NC7000 —	10.5@8.6 GHz -15@8.7 GHz -17.6@8.8 GHz	8.4–8.6 GHz 8.5–9 GHz 8.6–11.1 GHz	[41]
3	Glass fiber reinforced epoxy	MWCNT	0 — 0.5 — 1 — 1.5 — 2 — 2.5 — 3 —	-5@3 GHz -16@3.1 GHz -19@3.1 GHz -30@3 GHz -30.1@3 GHz -29@3 GHz -28@3 GHz	— 3–3.25 GHz 3–3.25 GHz 2.9–3.22 GHz 3–3.25 GHz 3–3.3 GHz 3–3.3 GHz	[44]
4	Epoxide resin (EP)	SiC and CB	40%SiC +5%CB 40%SiC +10%CB 40%SiC +15%CB 50%SiC +5%CB 60%SiC +5%CB	-18@12.8 GHz -9.8@12 GHz -5@8.9 GHz -40@9.5 GHz -16@8.1 GHz	11–16 GHz — — 7–13 GHz 6.5–13 GHz	[47]

magnetization. Those ion solutions absorbed the fibers uniformly after 14 h of immersion and the iron oxide nanoparticles formed inside the fibers' micro-pore structures. By adding iron oxide particles in to kenaf fibers, the shielding efficiency of kenaf composites was improved. Optimum shielding efficiency of kenaf fibers was seen with 18% Fe content. Electromagnetic, mechanical characterization and fractography of iron reinforced jute fiber composites were studied by Kala et al. [61]. The first sample was 20:35:45, the second 20:40:40, the third 20:50:30 and the fourth sample was 20:55:25 percentage of jute, iron and epoxy respectively. The iron powder was mixed manually with epoxy resin for 30 min in distinct proportions as required in the composite and followed by ultrasonic mixing for 30 min. With the ratio of jute:Iron:epoxy 20:50:30 was the best microwave absorber around an average of 98.1% which has a thickness of 6 mm and wide band. The thickness of these composites also really matters.

For microwave absorption, Ni/C porous fibers were produced utilizing a simple in situ template approach with jute fiber as the raw material. Jute fibers were submerged in an aqueous solution of Ni (NO₃)₂ at a certain concentration. The wet jute fiber was extracted with tweezers and dried following soaking for 24 h to generate Ni/C porous fibers. Under the same circumstances, the jute fiber was annealed. The produced Ni/C porous fibers displayed outstanding microwave absorption capability with thickness (1.5–3.5 mm) to get porous carbon fiber, which was named PCF [62]. Figure 4 shows clearly for PCF with 2 mm thickness, shows the maximum reflection at 13 GHz and 1.5 mm thickness at 18 GHz. For this type of material, the thin material is more effective for higher frequency. For Ni/C-0.2, the maximum reflection was recorded with 3 mm thickness and was -44 dB at a frequency of 8 GHz.

For green fiber-based composites, the influence of manufacturing technique is oversimplified, and its impact on electromagnetic characteristics was not compared with that of the same samples to determine the ideal manufacturing technique. However, future research will concentrate on this. In accordance with Table 2, magnetron sputtering offers excellent potential for electromagnetic absorption. When the electromagnetic and mechanical properties are in concern, manual mixing or mechanical mixing is also beneficial.

2.3 Effect of iron based additives on microwave absorption

Gultom et al. [63] used Natural zeolites which contains 80.3% SiO₂, 14.19% Al₂O₃, 0.91% Fe₂O₃ and ferric oxide as fillers in the microwave absorptive polyurethane composites. Ferrite-oxide particles have excellent microwave absorption properties, however, the ratio of zeolite to ferric-oxide influenced the optimal microwave absorption. Fe ion-doped SnO₂/(MWCNTs) composites were produced and their microwave characteristics was investigated by Bayat et al. [23], and 48.8% Fe ion shows a minimum (RL) of -44.5 at 15.44 GHz with a thickness of 1.5 mm. For Ku band, the lowest RL, -10 dB was recorded at 4.5 GHz. Hussein et al. [64] also discussed the microwave absorption and shielding capabilities of (MWCNT) composites chemically modified with metal or metal alloy oxides and put in a polyurethane matrix. As a consequence, all metals, especially CoFe at 20% concentration increased the reflection loss from 10% to 20%. Zhang et al. [65] also provided another assessment on the microwave absorption capabilities of Fe@carbon fiber, with the research finding that a composite loaded with 30% carbon fibers@Fe got as the best microwave absorption. Ben

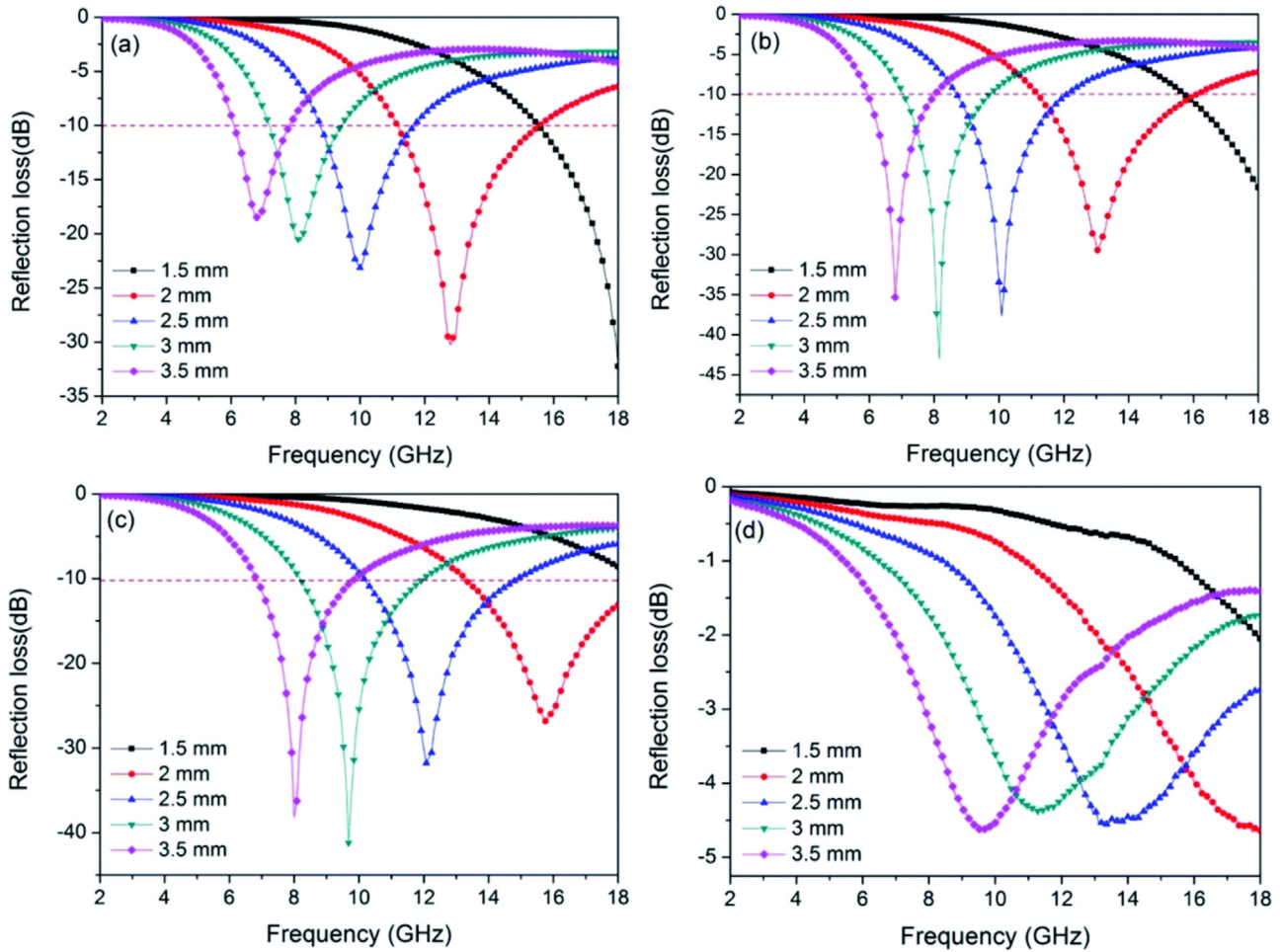


Fig. 4. Frequency dependence of the reflection loss curves for (a) PCF, (b) Ni/C-0.2, (c) Ni/C-0.5, and (d) Ni/C-1.0 with different thicknesses under the permission of [62].

Ghzaïel et al. [66] also found another micro wave absorber for KU-band by Pani/BaFe₁₂O₁₉ Polyaniline/substituted barium hexaferrite. Another researcher Jeon et al. [67] observed Composite with 2.0 wt.% of graphene oxide (GO) exhibited about -56.4 dB @10.8 GHz and 5.1 GHz for graphene oxide (GO) sheets capsulated on carbonyl iron particles (CIP) which produced by wet stirring procedure. Wu et al. [68] also investigated the microwave magnetic characteristics of Co₅₀/(SiO₂) 50 nanoparticles for 0.1–18 GHz frequency range and found that they are only good for low frequencies.

Gao et al. [69] published another work on the mechanical properties and microwave absorption of layered carbonyl iron powder-poly (vinyl chloride) composites. For single-layer samples, the microwave absorbing of carbonyl iron powder poly vinyl chloride (PVC/CIP) composites increased with the increase of CIP content. Alternating multiple samples have greater microwave absorption quality than single-layer samples with the same CIP concentration. Sun et al. [70] also examined and characterized for electromagnetic wave absorption of core-shell structured Fe₃O₄-polyaniline nanoparticles with particle size 72.4 nm for Fe₃O₄, and with a 1.7 mm thick layer. An ideal reflection loss of -35.1 dB was recorded at

16.7 GHz. Fe₃O₄-PANI nanoparticles may be promising candidates for use in EMW absorption, according to the findings.

Panwar et al. [71] also developed low-cost broadband radar wave absorber with different types of mineral dust. The first (brown in color) with content Fe₂O₃ (72.5%), ZnO (19.9%), MgO (7.6%), type 2 (black in color) with the content Fe₂O₃ (57.7%), ZnO (6.7%) MgO (18.5%), mineral dust type 1 (70 wt%) + Beach sand (30 wt%) with the content C (17.1%), TiO₂ (43.2%), SiO₂ (56.8%) Mineral dust type 2 (70 wt%) + Beach sand (30 wt%). Among this, mineral dust type 1 with 3 mm thickness shows excellent absorption for long range. It showed more than 90% absorption for the frequency range 8 GHz to 11 GHz, and this mainly by higher content of Fe₂O₃. Additionally, by making two or three layers, it was possible to increase the absorbing capacity to RL of -27.20 (dB) and -32.58 (dB) respectively. Shah et al. [72] also did EM characterizing of Fe nanoparticle/Carbon Fiber/Epoxy Resin Composite Plates. With 30 wt% Fe nano particles (NPs) and Vertical arrangement of CF showed -16.2 dB @6.1 GHz and -13.1 dB @15.6 GHz. However, 20 wt% Fe NPs with CFs (Parallel arrangement of CF and incident wave) shows -10 dB (7.5 GHz). The composite with 40 wt% Fe

Table 2. Natural fiber based micro wave absorber with different manufacturing and additive loading.

No.	Bulk material	Additive	Method of manufacturing	Recommended amount or method	RL min. (dB), or Absorption in%	Frequency range for RL < -10 dB	References
1	Hemp fiber mats	Al sheet	Laminate assembly layer by layer	Hemp fiber with two layers Hemp fiber with three layers Two Hemp fiber with one Al layers Two Hemp fiber with two Al layers	82.7–89.9% 70.2–83.0% 20.6–47.4% 19.4–44.0%	– – – –	[58]
2	Kenaf fiber composites	Cu	Magnetron sputtering	0.5 hr. magnetron sputtering– 1hr. _____ 2hrs. _____ 3 hrs. _____	–23.8 dB, –32.5 dB, –43.3 dB, –48.3d B	8 –12 GHz 8 –12 GHz 8 –12 GHz 8 –12 GHz	[59]
3	Kenaf fiber- composites	Fe	Fiber magnetization	6.8%, _____ 15.9% _____ 18% _____	60–70% 65–75% 75–80% @9 to 11 GHz	– – –	[60]
4	jute fiber composites	iron	iron powder was mixed manually with epoxy resin	jute: Iron: epoxy ratio 20: 35: 45 _____ 20: 40: 40 _____ 20: 50: 30 _____ 20: 55: 25, _____	–27 dB for thickness value 8.5 mm@12 GHz –34.8 dB for thickness value 8.5 mm@11 GHz –19 dB for thickness value 8 and 8.5 mm@9.8 and 10.8 GHz –15 dB for thickness 6 mm@11.1 GHz	11.5–12.4 GHz 10.5 – 11.5 GHz 10–11.25 GHz for 8 mm, 9–9.5 GHz for 8.5 mm 10.5–12 GHz	[61]

NPs with CFs (Parallel) showed less than –10 dB from 14 GHz to 18 GHz and the minimum recorded was –24 dB @17.9 GHz for a plate thickness of 4.10 mm to 4.48 mm.

Table 3 demonstrates that SnO₂/MWCNT composites with 48.8% iron concentration and (GOCIPs) with increased GO concentration to 2% exhibit extremely favorable microwave absorption. And it is evident that carbon-based composites require relatively little concentration, in contrast to composites with iron-based additives, which require greater concentration to have outstanding electromagnetic properties. However, because of parameter inconsistency, it is challenging to draw a judgment using such forms.

Wang et al. [74] used in situ synthesis, densification, and magnetron sputtering methods for a natural fiber-based sandwich-structured magnetic composite. The iron oxide's particle size in the core layer of the magnetic composites was 135 μm , and the total iron oxide content was 18.7 wt%. The interlayer surface had an iron oxide particle size of 492 μm , and the total iron oxide content was 26.1 wt%. 0.8 mm thick composite insulated about 99.2% of the electromagnetic radiation. Carbon fibers of three various lengths (80, 150, and 350 μm), two different fiber densities (1000 and 2000 fibers/ mm^2), along with two different quantities of Fe₃O₄ nanoparticles were used to study the effect (0.5 and 1 wt%) on EM properties. Composite with micro carbon fibers of 350 μm length and a density of 2000 fibers/ mm^2 with 1 wt.% of Fe₃O₄ nanoparticles had the highest total SE value [75].

Carbonyl iron particle composite with graphene oxide exhibited the lowest reflection loss but in medium frequency in the other hand, MWCNT composite with iron particle shows minimum reflection loss for relatively higher frequency as shown in Figure 5. Glass fiber with MWCNT shows its RL min with minimum frequency. From this graph it is clear that for increased frequency using both iron and carbon-based additives in the same time is effective. The composites for Figure 5 are selected with the best performance and concertation.

3 Effect of carbon and iron-based additives on mechanical behavior of composite materials

While targeting to improve the microwave absorption capability of materials using additive nanofillers, it is worthwhile to examine the effect of inclusion of nanofillers on the mechanical behavior of the reference/pristine materials to identify the best concertation that could enhance or reserve the reference performances, i.e., strength, fracture toughness, and stiffness. In this regard, there has been a limited researches that have used the same sample for both mechanical and microwave absorption studies; however, various bulk materials with these nano additions, i.e., carbon-based and iron-based actives, are being reviewed to correlate the effect of these additives in microwave absorption without affecting the mechanical

Table 3. Representative summary of iron-based filler.

No.	Base Material	Additive type	Loading wt.%, RL min. thickness	References
1	Polyurethane	Natural zeolites and ferric-oxide	Nano zeolite: ferric oxide 18:2——— -7.3 dB@9.9 GHz 16:4——— -12.2 dB@9.9 GHz 14:6——— -9 dB@11.1 GHz 12:8——— -13.2 dB@11.1 GHz 10:10——— -2 dB@11.1 GHz	[63]
2	SnO ₂ /MWCNTs composites	Iron	16.2%, — -13 dB@8.5 GHz with 2 mm thickness 29.2%, — -12.5 dB@12 GHz with 1.5 mm 39.8%, — -22.5 dB@13.7GB with 1.5 mm 48.8%, — -44.5 dB@15.44 GHz with 1.5 mm	[73]
3	(MWCNT) composites	Fe.	5% -14 dB@6 GHz with 3 mm thickness 10% and -14 dB@6 GHz with 2 mm 20% -28 dB@18 GHz with 1 mm -24 dB@50 GHz with 0.4 mm and -22 dB@25 GHz with 0.8 mm	[64]
4	Paraffin wax	Fe@CF	20% -22.5 dB,@9 GHz with 3 mm thickness 30% 40% -36.89 dB@6.2 GHZ with 2.5 mm -17.24 dB@7.8 GHZ with 2.5 mm	[65]
5	Fe ₃ O ₄ -PANI nanoparticle-paraffin composite	Fe ₃ O ₄ nanoparticles	1 mm -5 dB@@16.5 GHz 1.5 mm -16 dB@18 GHz 1.7 mm -35.1 dB@16.7 GHz. 2 mm -15 dB@16.5 GHz 2.5 mm -15 dB@9 GHz 3 mm -15.5 dB@6.5 GHz 3.5 mm -15 dB@5 GHz 4 mm -15.5 dB@4.2 GHz 4.5 mm -15 dB@3.9 GHz 5 mm -15 dB@3 GHz	[70]
6	Carbonyl iron particles (GOCIPs) composites	graphene oxide (GO)	0% -16 dB@18 GHz with 1.5 mm thickness 0.5% -25 dB@18 GHz with 1.5 mm 1% -39 dB@18 GHz with 1.5 mm 2% -56 dB@10.9 GHz with 1.9 mm	[67]

and fracture behaviors for the production of strong radar material. Carbon nanotubes also increased damage tolerance for radar absorbing structure and prevent material damage [76]. Flame retardant self-healing, shielding and fiber modification are some applications of nanotechnology for fiber-reinforced polymer composites [77]. The impact of nano-scale materials (carbon nanotubes and oxide nanoparticles) on the mechanical properties of nanocomposites with various metallic and polymeric matrices, was also studied by Fathi et al. [78] and concluded that mechanical characteristics like fracture toughness, hardness, tensile and flexural strength, was improved. Different carbon and metallic fillers introduced by researchers. For example; Abu-Okail et al. [79] introduced graphene and alumina nanoplatelets on carbon/glass and studied the mechanical characteristics. The results showed good properties in hardness, tensile strength and bending strength.

3.1 Effect of carbon-based nano particles on mechanical behavior of composite material

Research on nano-carbon materials, including fullerenes, CNTs, CNFs, and graphene, has been a focus of nanoscience over the past two decades and was used in a variety of applications [80]. Jelmy et al. [44] did the addition of conducting fillers to epoxy matrix reinforced by glass fiber and improved the mechanical properties, because of the high aspect ratio and highly elastic behavior of CNTs during loading and the strong interfacial bonding between epoxy and PANi-coated MWCNTs. Failure strain, hardness, strength, and modulus were also determined by Nezhad et al. [81] by using graphite carbon nanoparticles (CNPs) implanted in a low viscosity epoxy resin with a CNP weight percentage (wt%) between 1 and 5%. The integration of 1 and 2 wt% of CNP increased the

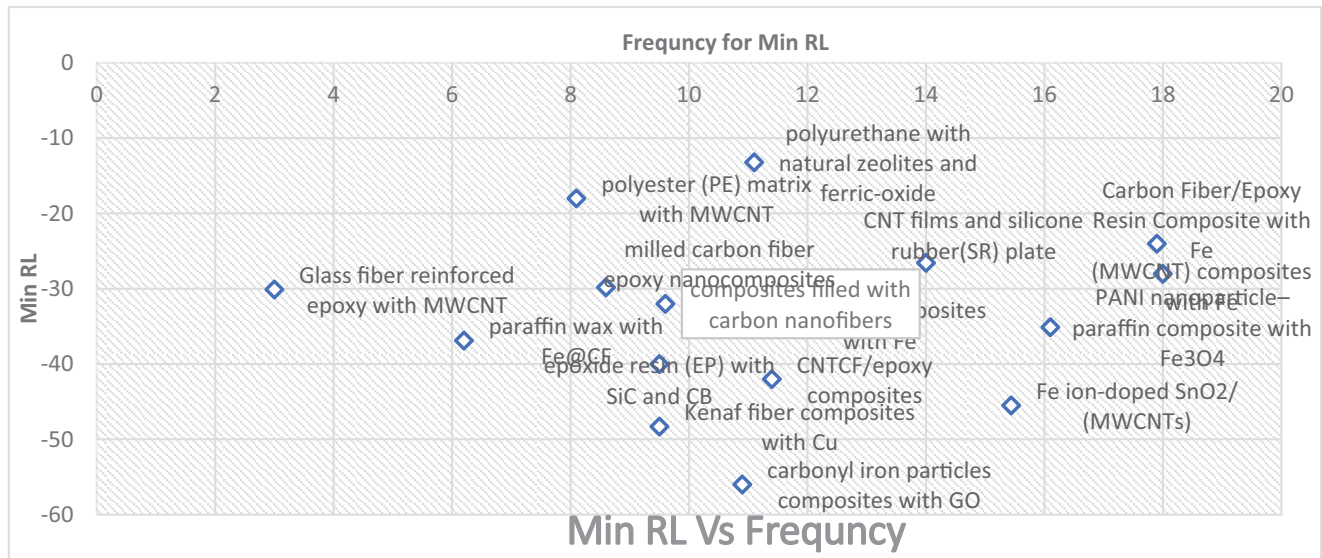


Fig. 5. Min RL vs frequency.

mechanical performance, however 5 wt% CNP had the opposite effect. This is mostly because of the morphological changes brought on by the rising CNP wt%, including re-agglomeration. Megahed et al. [82] added 0.5 wt% silica (SiO_2), 1 wt% SiO_2 , 0.5 wt% carbon black (C), 1 wt% C, 0.25 wt% $\text{SiO}_2 + 0.25$ wt% C, and 0.5 wt% $\text{SiO}_2 + 0.5$ wt% C to test the tensile strength of glass fiber reinforced composites. The outcome revealed when compared to neat glass fiber reinforced epoxy composites, the incorporation of all nanoparticle contents increased on/off axis ultimate tensile strength, failure strain, tensile modulus, and toughness except for the hybrid nanocomposites reinforced with 0.5 wt% SiO_2 and 0.5 wt% C simultaneously. With 0.5 wt% C, the highest on-axis ultimate tensile strength was achieved, when compared to clean glass fiber reinforced composites, a gain of 18–79% was made. Carbon nano tubes have demonstrated their usefulness in improving the mechanical and water absorption capabilities of bamboo and ramie fiber reinforced polymer composites [83].

Rasoolpoor et al. [84] and Naghizadeh et al. [85] studied low and high velocities impact performance, respectively. Adding carboxyl-modified multi-walled carbon nanotubes (COOH-MWCNTs) to the sandwich panels with three different weight percentages of 0.3, 0.5, and 1 wt% of COOH-MWCNTs was done. Furthermore, increasing the COOH-MWCNT composition increased high and low velocity impact response of composite materials.

The effect of crab shell with a carbon content of 24.53% and CaO content of 71.42% [86] particles with 0 wt%, 2 wt%, 4 wt%, and 6 wt% on sisal based hybrid composites was explored by Soundhar et al. [87]. In comparison to other combinations, the addition of four weight percentages of crab shell particles improved the tensile strength by 50% and flexural strength by 38% significantly. Further addition with 6%wt decreased relative to 4% however, it slightly increased relative to pristine.

Rehman et al. [88] also did on influence of micro-crystalline cellulose (MCC) particles on jute fiber reinforce epoxy composite, which has a carbon content of 66.62 % [89] with loading (0%, 1.5%, 3%, 5%, 7%, 9%, and 11%). The result showed adding 3%, 4%, 5% was the best and adding higher percentage led to decrease the mechanical properties due to agglomeration and higher percentage induced damage. It's worth noting that adding up to 7% MCC improved the tensile strength and modulus by 48 and 25.6%, respectively.

Bhowmik et al. [90] did experiments on the effect of (MWCNT) on the mechanical behavior and damage of woven carbon fiber reinforced epoxy composites. Both MWCNT/epoxy nanocomposites and (CNT) reinforced laminated open hole composites with various MWCNT weight ratios underwent tensile tests. For MWCNT dosage of 0.5, 1.0, and 1.5 wt%, respectively, the tensile modulus of CNT/epoxy nanocomposite was increased by 15.0%, 37.86%, and 22.86%. Tensile strength was raised by 19.76%, 25.78%, and 6.70%, whereas the comparable improvements in tensile modulus for woven composites were 3.45%, 10.25%, and 1.53%. Due to MWCNT agglomeration, the improvement of mechanical properties was reduced for 1.5 wt% MWCNT laminates. Another interesting research was done by Ismail et al. [91] on addition of MWCNT in amounts of 0 wt%, 0.5 wt%, 1 wt%, 1.5 wt%, and 2 wt% for flax hybrid bio-mechanical composites which may use in aircraft structural applications. According to the experimental findings, MWCNTs increased the composite flexural strength by 2.8–50%. Nor et al. [92] also investigated the effects of MWCNT on bamboo/glass fiber hybrid composites. The presence and quantity of CNTs had an impact on the hybrid composites' tensile strength and modulus. The addition of CNTs (0.1 wt%) improved tensile strength of pure epoxy by 16.4%. CNT content increases of 0.1, 0.3, and 0.5 wt% showed improved tensile strength (by 1.7%, 4.7%, and

Table 4. Representative summary of the effect of carbon-based additives on mechanical properties.

No.	Bulk Material	Additive percentage	Mechanical properties measured	Measured value	References
1	Epoxy resin	CNTs 0wt%..... 1wt%..... 2wt%..... 5wt%.....	Compressive strength (MPa)	79.8479.86 90.569.4	[81]
2	Bamboo/glass fibre hybrid composites.	CNTs 0wt.%..... 0.1wt.%.... 0.3 wt.%.... 0.5 wt.%.... 1.0 wt.%....	Tensile strength (MPa)	74.03875.31877.540 79.76346.797	[92]
3	Bagasse /glass fiber/cement composites	(MWCNTs) 0wt.%.... 0.5wt.%.... 1wt.%.... 1.5wt.%....	Impact strength(J/M ²)	24002500 27002600	[94]
4	Epoxy resin	Carbon black 0wt.%..... 1wt.%..... 2 wt%..... 3wt.%.... 4wt%..... 5 wt. %...	Flexural strength (MPa)	74808484 9870	[96]
5	Epoxy resin	Graphene oxide 0wt.%..... 1.5wt.%..... 3 wt%..... 4.5wt.%.... 6wt. %...	Tensile strength (MPa)	7 13987.5	[97]
6	CNT spun yarns Epoxy resin	long carbon nano-tubes (CNTs) 0%..... Vf of 19.7% ... Vf of 19.7% ... Vf of 19.7% ... Vf of 19.7% ...	Tensile strength (MPa)	175212262 284467	[98]

7.7%). Tensile strength was 79.763 Mpa using 10% bamboo fiber and 0.3% CNT; however, adding 1% CNT reduced the tensile strength to 46.797 Mpa. Adding MWCNTs improved the mechanical and fracture properties of ramie fiber-reinforced composites, increased the flexural strength to 34% at 0.6% MWCNT [93]. Kordkheili et al. [94] did research by adding similar nano particle which was MWCNT however, different hybrid composites, bagasse and glass fibers. The composites with the highest modulus and flexural strength were those with 1.5% MWCNTs and 10% glass fiber. The panels with 10% bagasse and glass fibers and 1% MWCNTs had the highest unnotched impact strength.

Rajmohan et al. [95] also did hybrid banana-glass fiber reinforced composites and the effect of CNT on tensile, compression and flexural strength. Adding of CNTs with 0.5% and 1% increased the tensile strength from 196

(N/mm²) to 238 (N/mm²) and 278 (N/mm²) respectively. The compressive strength also increased from 108 (N/mm²) to 122 (N/mm²) and 142 (N/mm²). Table 4 shows a representative summary of on carbon-based additives on mechanical properties of composite material and shows the optimum concertation for best additive percentage.

3.2 Effect of iron-based additives for mechanical behavior of composite materials

Nanotechnology has inspired a lot of interest in numerous fields of research for the last two decades, especially for the development of nanoscale materials which made using a variety of approaches, such as physical or chemical procedures[99]. For example Bafakeeh et al. [100] did research using Al₂O₃, and Wang et al. [101] used silver

Table 5. Representative summary of the effect of iron-based additives on mechanical properties.

No.	Bulk Material	Additive Percentage	Mechanical properties measured	Measured value	References
1	Acrylonitrile-butadiene-styrene copolymer (ABS)	CIPs 0 wt.% 10 wt.% 20 wt.% 30 wt.% 40 wt.% 50 wt.% 60 wt.%	Tensile strength (MPa)	44 40.5 41 41 44.5 40 36	[22]
2	Amino-silane treated e-glass fiber reinforced epoxy	Si-iron (III)oxide 0 wt.% 0.5 wt.% 1 wt.%	Tensile strength (MPa) and inter laminar shear strength (MPa)	99 and 19 114 and 16 126 and 14	[107]
3	Epoxy-silicone resins	Carbonyl-iron particles 65 wt.% 70 wt.% 75 wt.%	Impact strength (kg.cm)	45 50 50	[119]
4	25% OPC Paste + 75% Standard Sand (Mortar)	Fe ₂ O ₃ nano particle 0 wt.% 2 wt.% 4 wt.% 6 wt.%	Flexural strength (MPa) with 28 days curing time	7.64 10.24 12.09 10.89	[120]
5	Carbon fiber reinforced epoxy	Fe nanoparticles 0 wt.% 30 wt.%	Flexural strength (MPa)	82.56 77.76	[72]

nitrate (AgNO₃) on woven carbon/glass fiber hydride composites and carbon fiber reinforced composite, respectively, which improved in tensile strength. Nkwaju et al. [102] also did research on iron-rich laterite soil with a chemical concentration of 35.33 wt% Fe₂O₃, 33.18 wt% SiO₂, and 17.89 wt% Al₂O₃ was utilized to make a geopolymer composite based on bagasse fibers. Mechanical, durability, and insulating qualities also investigated. The key mechanisms responsible for the geopolymer composite's loss of strength are fiber breakage and fiber-matrix interface, which leads to conclude that the increased laterite with high iron content, increased the mechanical proprieties. Feldshtein et al. [103] also used iron particles with the size of 200 µm and carbon (graphite) to prepare iron-based composites with alumina and zirconia nano additives and showed adding alumina nanoparticles to this base material reduced the strength of composite materials. Because of their superior hardness and thermal stability, Al–Cu–Fe alloy powders can be used as an efficient reinforcement particle for elemental Al-based composites. Both ultimate tensile and yield strength were raised over the equivalent Al matrix values [104].

Piffer et al. [105] discussed how adding iron ore tailings (IOTs) to polypropylene and maleic anhydride grafted polypropylene (MAPP) composites affects their mechanical, thermal, and morphological qualities. The modulus of elasticity increased with IOT content for both types of polymers, whereas the impact and ultimate tensile strength

of the composite dropped. Arun Prakash et al. [106] also did another interesting research on the influence of Iron (III) oxide particles between 0.5 and 1.0 vol.% on E-glass fiber as received and siliconized glass fiber reinforced epoxy composite. The highest tensile strength was achieved by 0.5 vol.% dosage of iron (III) oxide particles with treated glass fiber and 800 nm, compared to 1 vol.%, 100 nm, and 200 nm particle sizes. This concentration with a particle size of 200 nm produced the highest recorded value for flexural strength. Dinesh et al. [107] used a magnetic stirrer to mix quantitative epoxy resin with 5 and 10% unsaturated polyester (UP) to make E-glass Fibre/Iron (III) oxide composite material. A fixed amount of UP/Epoxy blend (10–90 vol%) was combined with 0.5 and 1.0 vol% silane treated iron (III)oxide. In addition, 40% silane-treated e-glass fibre was installed, along with a particle-strengthened UP/epoxy blended system. The tensile strength was increased from 114 Mpa to 126 Mpa in 100/10/40/0.5 and 100/10/40/1.0 as epoxy/UP/Si-fibre/Si-iron (III)oxide vol% composition. From pristine type the tensile strength recorded was 73 Mpa. However, for 0.5–10 wt%, it decreased the flexural strength of this composite. Increased in Si-iron (III) oxide increased the inter laminar shear strength to 16 Mpa from 14 Mpa. Iron filing in the concentration of 5 wt%, 10 wt% and 15 wt% was used in [108] to reinforce polystyrene based resin (PBR). The young's modulus (N/mm²) was increased from 335.72 ± 0.63 to 484.41 ± 0.96 for 5 wt%, to 630.15 ± 1.47 for 10 wt% and 1131.80 ± 1.84 for 15 wt%.

Adding iron powder to natural fiber reinforced composite and E-glass fiber reinforced composite decreased the tensile strength and flexural strength as per [61,109]. For example in [109] with the addition of 0.5 vol.% and 1.0 vol.% Fe_2O_3 , the tensile strength of E-glass fiber reinforced composite reduced from 135 Mpa to 128 Mpa and 114 Mpa, respectively, and the hardness increased from 84 to 88 for both samples. Julyes Jaisingh et al. [110] also investigated Iron (III) oxide nano particles effect on the mechanical properties of Kevlar Fiber Reinforced Epoxy Nanocomposites. Tensile strength of the silane modified iron (III) oxide nano particles reinforced composite sheets was significantly higher than that of the base composite (without iron (III) oxide). There was an increase in strength at minimal loading (less than 1.5 wt%), however, when the loading has increased by more than 1.5%, the rate of decline begins. Unfortunately, when the concentration was increased above 2.5 wt%, the strength was lower than that of pristine Kevlar Fiber Reinforced composites.

Shah et al. [72] investigated effect of Fe nanoparticle on flexural properties of carbon fiber/epoxy resin composite plates. Flexural strength of pure epoxy resin and CFs plates were 82.58 MPa at 3.81% deformation, while the flexural strength of ER, CFs, and 30 wt% Fe NPs plates was 77.78 MPa at 3.74% distortion. Additions of Fe NPs are not effective on the flexural strength and flexural strain of nanocomposite plates. $\text{Fe}_3\text{O}_4/\text{GO}$ considerably improved the mechanical properties of epoxy like young's modulus, fracture toughness KIC, and impact strength of epoxy however, decrease the thermal expansion [111]. Yadav et al. [112] also showed Iron oxide platelets and graphene oxide (GO) showed powerful synergistic effect on strengthening the chitosan matrix. As 0.5% Fe_3O_4 and 1% GO are added to the composite, the tensile strength and Young's modulus increase by around 28% and 74%, respectively, when compared to chitosan.

To prepare cellulose nano fibers reinforced polyhydroxybutyrate(PHB)/Polycaprolactone(PCL)/ Fe_3O_4 shape memory polymer composites, 3D printing technology was used to combine PHB, nano iron oxide (Fe_3O_4 , 99.5%, 20nm), and cellulose nanofiber dispersions (CNFs, 1.1 wt%) in [113]. Fe_3O_4 and CNFs were studied for their effects on characteristics such as thermomechanical, static and mechanical behaviors. PHB/PCL (80:20) composites containing 10% Fe_3O_4 and 0.5 wt% CNFs had the best overall mechanical and magneto-responsive shape-memory capabilities, according to the findings. The polymer matrix used was high density polyethylene (HDPE), polypropylene (PP), and polystyrene (PS), with metal Fe powder in 5, 10, and 15 vol% to produce iron filled polymer composites in [114]. The hardness of HDPE was raised more than that of polypropylene (PP), and polystyrene when Fe powder was added. PS-Fe composites outperformed HDPE-Fe and PP-Fe composites in terms of yield, tensile strength, and modulus of elasticity. In all matrixes, increasing the Fe concentration from 5% wt% to 10% wt% and 15% wt% decreased the yield and tensile strength. Reis et al. [115] also examined the fracture properties of aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) nanoparticles distributed in epoxy matrices at weight fractions of 3%, 5%, 7%, and 10%. The inclusion

of both Al_2O_3 and Fe_2O_3 nanoparticles into the epoxy matrix enhanced the modulus of elasticity, fracture toughness, and fracture energy. 3.0 wt% content showed the greatest results as a toughening for both nanoparticles. Amorphous shape $\text{Fe}_{52}\text{Cr}_{15}\text{Mo}_{26}\text{C}_3\text{B}_1\text{Y}_3$ particle was used to reinforce pure aluminum (Al) matrix, by X. Zhou, et al. [116]. The Fe-based amorphous powder was fully mixed with pure Al powder at 5%, 10%, 15%, and 20%. When the reinforcement content was 15%, the maximum tensile strength increased by 154% higher than that of pure Al. Sun et al. [117] also tested the mechanical properties of an epoxy nano composite (ENC) reinforced with Fe_2O_3 nano particles (NPs). 4 wt% modified Fe_2O_3 NPs increased the tensile strength by 50.2% and fracture toughness by 106%, based on a single-edge notch bend test. Water absorption was improved as iron oxide nanoparticles added to medium density fiberboard which produced from urea-formaldehyde resin and poplar wood fibers [118]. Table 5 shows a representative summary of on iron-based additives on mechanical properties of composite material to show the optimum concentration for best additive percentage.

Generally, the use of metallic reinforcements to improve mechanical performance in metal matrix composites is also futuristic. For Al matrices, it was discovered that Fe, Ni, Ta, and metallic glasses, which are primarily used as metallic reinforcement, result in a change of mechanical properties that are somewhat better than ceramic reinforced AMCs however, lower than the unreinforced Al matrix [121].

4 Conclusion and future look

The review reported in this paper was to address the particle loading in radar absorbing materials. With limited information available that investigated both EM and mechanical properties of nano-modified composite materials, the authors attempted to highlight relatively optimal carbon and iron nano-particles for producing strong radar materials.

The following conclusions are drawn from the review conducted:

- Both iron and carbon-based additives increase the radar absorbing and some mechanical properties of composite materials. However, it is very important to have the optimum concentration and must be studied for selecting the weight percentage to compensate both properties.
- Glass fiber reinforced composite is not effective for radar absorbing material, even if low content CNT is applied as its frequency range for $\text{RL} < -10\text{ dB}$ is very low.
- For the sandwich structure made of Al and natural fiber reinforced composites, adding natural fiber plate can increase the electromagnetic wave absorption and the mechanical properties of the total composite.
- Addition of Carbon Black and carbon nano fiber in moderate percentage from i.e. 5–10% of loading in the matrix increases electromagnetic wave absorption, however for different types of CNT, smaller percentage loading shows good radar material properties recommended to apply less than 3%. Lower concentrations of these CNTs are good for lower frequencies and higher

percentage in CB and CF can be applied for higher frequencies. The particle size and shape of these carbon-based nano additives also affect the electromagnetic properties and smaller size is preferred. In addition, the fiber length, angle of orientation also affects the electromagnetic properties as the impedance of the laminate is substantially lower than that of air for parallel alignment. Green carbon-based particles like corn, charcoal and natural fibers are also promising additives if different manufacturing techniques and dielectric materials are applied to these materials. Thickness of micro wave absorbing material is also one determining factor so that finding the preferred thickness is needed to be chosen for a specific working frequency. Adding CNTs are also promising in natural based carbon composites to produce green microwave absorbers.

- Adding di-electric additives in radar absorbing material also increases the electromagnetic absorbing properties, among these materials iron particles is the most common. Higher loading of iron particles shows good electromagnetic absorption, i.e., more than 20% of total volume.
- Smaller amount of particle loading is recommended for improving mechanical properties and seen in both iron and carbon-based additives relative to electromagnetic absorbing applications.
- Applying both iron and CNT can produce a thin absorbing material. Multiwall carbon nanotube (MWCNT) composites functionalized with metal or metal alloy oxides and embedded with polymer matrix also show good electromagnetic absorbing properties.
- These nano particles may affect the bulk material negatively for both mechanical and electromagnetic properties unless, it is applied in proper conditions. These avoid agglomerations, maintain electrical, thermal properties and charge flow of materials are critical.

Generally, adding nanoparticles to composite materials typically improves its electromagnetic wave absorption, fracture toughness and mechanical properties, if proper manufacturing technique, loadings, size, and kind of nanomaterials are used. To better comprehend the properties of mechanical and electromagnetic waves, future research should concentrate on optimum concentration and mathematical correlations.

For mechanical qualities, a higher concentration of Nano addition is linked to agglomeration.

However, there is a lack of clarity on elector magnetic absorption, necessitating more research material.

Additionally, a combined understanding of physics and chemistry is required to understand the relationship between concentration and electromagnetic characteristics.

Conflict of interests

The authors declare no conflict of interest.

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