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Research Article

The Impact of Orientation Angle and Number of Layers on Electromagnetic Shielding Characteristics of Carbon Fiber Composites

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Abstract

In this study, electromagnetic shielding characteristics for orientation angle and number of plies of carbon fiber reinforced epoxy composites were investigated in the frequency range between 900 and 6000 MHz. Both unidirectional and bidirectional carbon fiber fabrics were utilized as reinforcement materials to manufacture the composite samples. Twill bidirectional glass fiber fabrics were also used in order to provide a large amount of flexibility. To prepare the composite laminates for measurement, hand lay-up method was preferred. Measurements were carried out by using DFG 4060 signal generator and HF 60105 spectrum analyzer. In the proposed frequency range, electromagnetic shielding effectiveness (EMSE) up to 62.13 dB was achieved. This value is accepted in the literature as a good level of shielding. According to the measurements, it was observed that EMSE was very higher when the orientation angle of the carbon fiber was 90°, as compared to 0°. Another parameter that affects EMSE is whether the carbon fiber fabric used is unidirectional or bidirectional because it was observed that the bidirectional fabric increased EMSE. In addition, it was determined that the number of plies has less effect on EMSE than the orientation angle.

Keywords: Carbon fiber; Hand lay-up method; Orientation angle; Electromagnetic shielding.

1. Introduction

Recently, due to extensive utilization of electromagnetic waves in electronic devices and communication equipment, electromagnetic interference (EMI) has become a serious issue [1]. It can cause important malfunctions in electronic systems. Especially in the military applications, malfunctions caused by EMI are vital, as there are critical platforms such as helicopters, battle tanks, unmanned aerial vehicles, frigates and jet aircrafts including electronic warfare and radar systems, control panels and avionics. Therefore, various materials have been used for the purpose of shielding critical systems and preventing safety problems [2, 3]. These materials are mainly conductor metals, surface spreading film materials coated metal, ferromagnetic materials, and composite materials [4]. Although the use of metals offers a high level of protection against EMI, it is not preferred in some industries, such as aviation [5-7] because there is a rising requirement to reduce aircraft weight and provide excellent mechanical properties, as well as a good level of electromagnetic shielding [6, 8]. Carbon fiber reinforced polymer composites (CFRP) are being increasingly used in EMI shielding due to their light weight, design flexibility, compression strength, and tensile strength [8,9]. In CFRP, the matrix is most often epoxy resin to bind carbon fibers together. Epoxy is a thermoset polymer that has low cost [10, 11]. Luo and Chung studied on carbon fiber reinforced carbon matrix composites, and they showed that shielding effectiveness of 124 dB was achieved in the frequency range between 0.3 MHz and 1.5 GHz. However, since carbon matrix materials are expensive, polymer matrix composites are preferred [12,13]. In some applications where a higher breaking point is required, glass fibers can also be used with carbon fibers.

The implementation of an EMI shielding material is decided by measuring its EMSE. EMSE can be expressed as the sum of three factors called reflection loss (R_{dB}), absorption loss (A_{dB}), and multiple internal reflections loss (M_{dB}). Reflection loss occurs due to impedance differences of two different media and depends on the electrical conductivity of the material. Absorption loss depends on the thickness and skin depth of the material. Multiple internal reflections loss is usually at negligible level. The illustration of EMI shielding mechanism is shown in Figure 1 [14]. The expression for EMSE, which includes R_{dB}, A_{dB}, and M_{dB} terms is given as:

$$EMSE_{dB} = 20\log\left|\frac{\eta_0}{4\eta_s}\right| + 20\log\left|e^{t/\delta}\right| + 20\log\left|1 - e^{-2t/\delta}\right| \quad (1)$$

In equation (1), the skin depth is related to frequency, relative permeability, and conductivity as:

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma_c}} \quad (2)$$

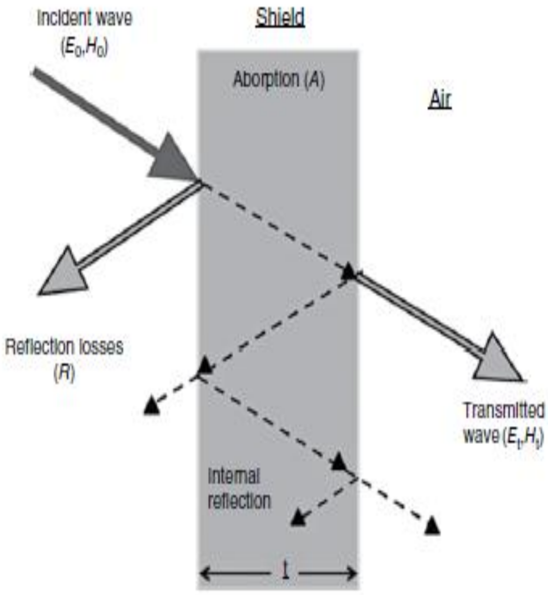


Figure 1. EMI shielding mechanism.

In this study, firstly, a total of eight carbon fiber epoxy composite samples with different orientation angle and number of plies were prepared, using hand lay-up method, and then measurements were carried out to investigate the effects of the orientation angle, the number of plies, and fabric type on EMSE in the proposed frequency range.

2. Experimental Setup

2.1. Sample Manufacturing

Unidirectional carbon fiber fabric with a real weight of 300 g/m² and epoxy resin, which consists of epoxy resin and hardener were employed to prepare first four laminates (25 x 25 cm). The volume fraction of carbon fiber was targeted to be in the range of 0.45-0.50. Total weight of epoxy resin was found by calculating its specific gravity. Epoxy resin and hardener were mixed in weight ratio of 5:3. In order to manufacture the four laminates designed with different stacking sequences, unidirectional plies were rotated in different directions at 90°. Configurations of samples of 2 plies and 3 plies manufactured in this way were arranged as [0°, 0°], [0°, 90°], [0°, 0°, 0°], and [0°, 90°, 0°]. All samples were manufactured by using hand lay-up method as shown in Figure 2.

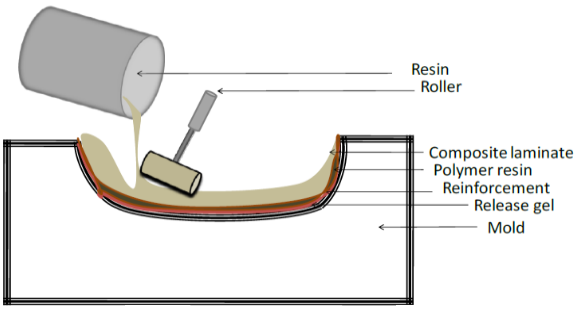
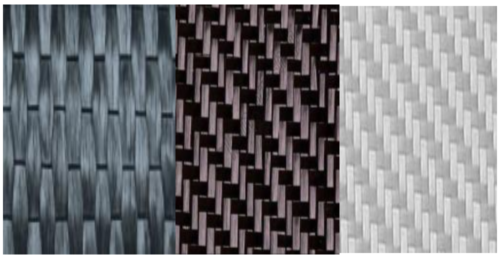


Figure 2. The schematic of hand lay-up method [15].

Bidirectional carbon fiber fabric with a real weight of 200 g/m², twill bidirectional glass fiber fabric and epoxy resin, which consists of epoxy resin and hardener, were employed to prepare the other four laminates (25 x 25 cm). The volume fraction of carbon fiber was targeted to be in the range of 0.35-0.40. Total weight of epoxy resin was again found from its specific gravity. Epoxy resin and hardener were mixed in weight ratio of 5:3. Configurations of samples of 2 plies, 3 plies, and 5 plies manufactured were arranged as [0°/90°, 0°/90°], [0°/90°, 0°/90°, 0°/90°], [0°/90°, $(0°/90°)_G$, 0°/90°], and [0°/90°, $(0°/90°)_G$,0°/90°, $(0°/90°)_G$, 0°/90°]. The subscript G represents glass fiber fabric.

The fiber fabrics used in the manufacturing process are illustrated in Figure 3.



(a) (b) (c)

Figure 3. Unidirectional and bidirectional fiber fabrics: (a) Unidirectional carbon fiber fabric, (b) Bidirectional 0°/90° carbon fiber fabric, (c) Bidirectional 0°/90° glass fiber fabric.

2.2. Measurements

The measurement method is based on the signal loss of the samples placed between the transmitting and receiving antennas. Firstly, the signal loss of the free space between the antennas was measured, and then measurements of the samples were performed. Electromagnetic shielding effectiveness (EMSE) of the samples was defined as the ratio between power received from interference source with no shield and power passing through the shielding material.

$$\text{EMSE}=10\log_{10}\frac{\text{Power received from interference source with no shield}}{\text{Power passing through the shielding material}} \tag{3}$$

EMSE measurement setup is illustrated in Figure 4.

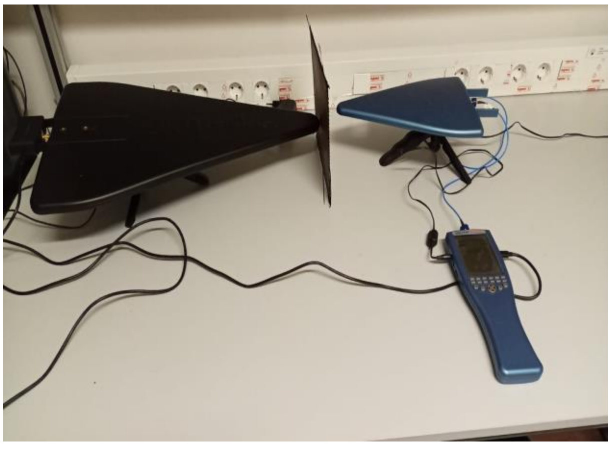


Figure 4. EMSE measurement setup.

As shown in Figure 4, there is a receiving antenna and a spectrum analyzer in left hand side, and a transmitting antenna and directional field generator in right hand side.

3. Results and discussion

The attenuation values in dB for the free space and the first four samples between the antennas are given in Table 1 [16].

Table 1. Attenuation values

Frequency (MHz)	Free Space (dB)	[0°,0°] (dB)	[0°,90°] (dB)	[0°,0°,0°] (dB)	[0°,90°,0°] (dB)
900	-18.82	-22.57	-28.14	-23.38	-27.87
1000	-26.77	-30.81	-34.74	-31.63	-33.51
1100	-18.16	-23.10	-28.74	-25.83	-27.74
1200	-24.55	-28.64	-36.41	-29.98	-34.14
1300	-11.25	-20.22	-31.57	-21.14	-33.11
1400	-10.23	-19.47	-33.03	-20.31	-34.80
1500	-11.20	-18.91	-40.52	-20.59	-33.47
1600	-10.01	-18.08	-36.55	-19.88	-33.95
1700	-11.11	-19.29	-33.88	-20.37	-35.82
1800	-10.44	-18.35	-34.14	-19.64	-35.14
1900	-10.48	-18.59	-34.79	-20.45	-36.29
2000	-8.07	-16.52	-35.01	-18.01	-36.01
2100	-11.01	-20.44	-38.61	-21.52	-40.69
2200	-10.69	-22.13	-41.06	-22.41	-40.97
2300	-9.98	-21.68	-47.78	-22.04	-43.61
2400	-11.46	-21.54	-48.46	-21.87	-45.24
2500	-4.89	-14.16	-48.03	-14.42	-41.70
2600	-16.75	-21.39	-50.77	-21.20	-49.84
2700	-16.28	-21.81	-47.86	-21.81	-61.93
2800	-16.52	-21.70	-50.26	-21.58	-49.90
2900	-15.67	-20.99	-54.34	-20.86	-47.15
3000	-17.27	-23.70	-57.96	-23.16	-51.72
3100	-16.58	-21.77	-50.01	-21.52	-50.42
3200	-16.97	-22.75	-50.30	-22.02	-47.84
3300	-17.29	-22.67	-62.32	-22.30	-61.66
3400	-17.10	-22.97	-55.79	-22.31	-60.07
3500	-17.51	-23.00	-61.06	-22.51	-52.43
3600	-25.64	-31.44	-64.77	-30.87	-66.24
3700	-15.80	-21.40	-61.55	-20.92	-59.91
3800	-15.90	-21.73	-55.55	-21.13	-60.38
3900	-15.51	-20.82	-65.59	-20.41	-61.75
4000	-14.93	-21.06	-56.47	-20.53	-54.60
4100	-14.31	-20.18	-59.35	-19.74	-61.80
4200	-15.53	-21.64	-59.76	-20.74	-57.93
4300	-15.48	-21.17	-69.29	-20.76	-60.89
4400	-15.08	-21.76	-60.27	-20.61	-56.74
4500	-14.89	-20.83	-59.74	-19.95	-62.90
4600	-15.77	-22.14	-60.80	-21.35	-69.98
4700	-16.89	-23.80	-59.60	-22.70	-58.53
4800	-15.47	-21.37	-60.46	-20.64	-63.96
4900	-15.12	-21.56	-66.66	-20.78	-75.46
5000	-16.03	-21.95	-64.93	-21.16	-59.01
5100	-15.80	-21.70	-67.32	-21.40	-75.05
5200	-15.37	-21.84	-60.37	-20.57	-64.73
5300	-15.45	-21.32	-64.54	-20.53	-57.23
5400	-15.28	-21.62	-69.26	-20.89	-69.98
5500	-16.06	-21.75	-66.33	-20.84	-71.26
5600	-14.27	-19.72	-65.53	-19.11	-56.91
5700	-15.73	-21.81	-65.22	-21.01	-66.48
5800	-17.14	-21.99	-67.04	-21.19	-60.19
5900	-15.38	-21.76	-63.90	-20.44	-58.04
6000	-14.38	-20.14	-61.16	-19.57	-67.62

As it can be seen in Table 1, the leftmost column gives the operating frequency. The next column shows the free space loss. The next 4 columns illustrate the received signal strength passing through carbon fiber materials with different orientation respectively, [0°, 0°], [0°, 90°], [0°, 0°, 0°], and [0°, 90°, 0°].

It can be seen from the table that orientation is highly effective. For example, at 900 MHz and [0°, 0°] orientation (both carbon fiber plies are in the same direction) loss is -22.57 dB; however, at [0°,90°] orientation (carbon fiber plies are perpendicular to each other) loss is -28.14 dB. As another example, if the operating frequency is selected as 6000 MHz, at [0°, 0°] orientation, loss is -20.14 dB, but, at [0°, 90°] orientation, loss is -61.16 dB. Therefore, it can be concluded that when the orientation is changed, loss will change too. Especially at 90° orientation angle, as electromagnetic wave propagation direction is perpendicular to fiber orientation, total loss increases because of increasing absorption losses. Moreover, as the operating frequency is increased, loss will increase enormously. The reason for this increase is that mechanism of shielding for conductive materials is absorption depending on decreasing skin depth in high frequencies.

Also it can be seen in the Table 1 that number of plies has affected the electromagnetic shielding effectiveness (EMSE). For example, at 2300 MHz and [0°, 0°] orientation (both carbon fiber plies are in the same direction) loss is -21.68 dB; however, at [0°, 0°, 0°] orientation (three carbon fiber plies are in the same direction) loss is -22.04 dB. As another example, if the operating frequency is selected as 6000 MHz, at [0°, 0°] orientation, loss is -20.14 dB, but, at [0°,0°,0°] loss is -19.57 dB. Therefore, it can be concluded that when the third layer is added in order to investigate the effect of number of plies of the composite samples on EMSE, loss will change less. According to the absorption loss equation, the ability to absorb electromagnetic waves of the materials depends on their thicknesses.

According to the measurements performed in the 900-6000 MHz frequency range, the attenuation graph of electromagnetic wave for [0°, 0°] and [0°, 0°, 0°] orientation is illustrated in Figure 5.

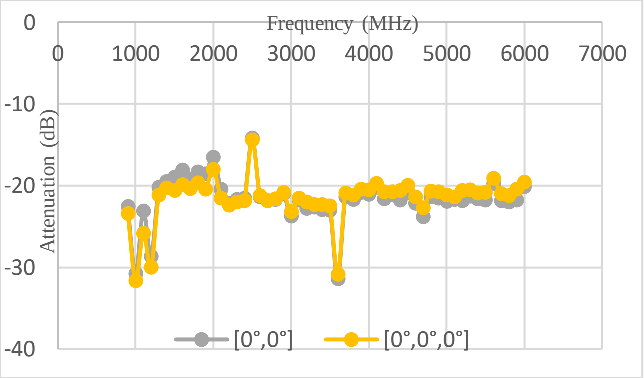


Figure 5. Attenuation for the samples in [0°,0°] and [0°,0°,0°] orientation.

As can be seen in Figure 5, there is almost the same pattern between 2-layered and 3-layered materials in the same orientation. According to the measurements performed in the 900-6000 MHz frequency range, the attenuation graph of electromagnetic wave for [0°, 0°] and [0°, 90°] orientation is depicted in Figure 6.

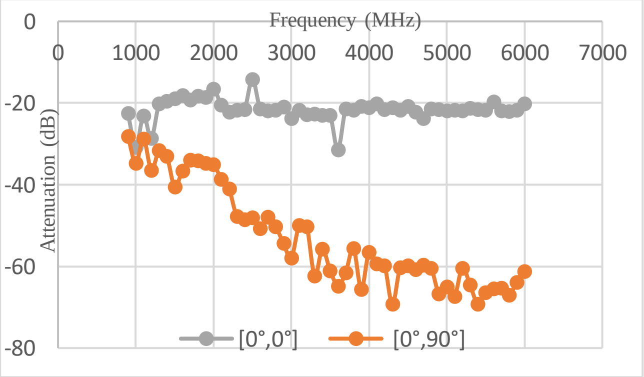


Figure 6. Attenuation for the samples in [0°,0°] and [0°,90°] orientation.

As can be seen in Figure 6, attenuation patterns of the materials are very different. Especially in high frequencies, there is approximately 40 dB difference. According to the measurements performed in the 900-6000 MHz frequency range, the attenuation graph of electromagnetic wave for the free space and [0°, 90°, 0°] orientation is demonstrated in Figure 7.

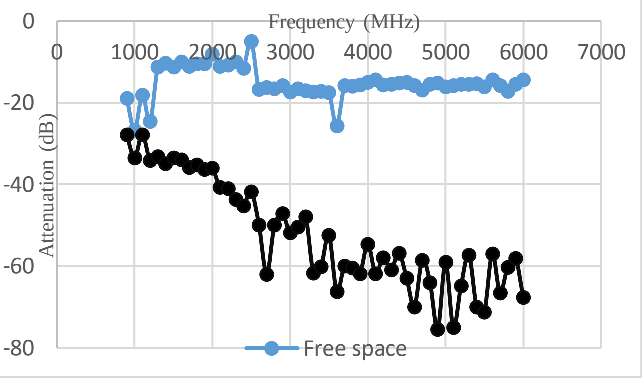


Figure 7. Attenuation for the samples in free space and [0°, 90°,0°] orientation.

As it is seen in Figure 7, attenuation patterns of the material oriented in [0°, 90°, 0°] and free space are very different. Especially in high frequencies, there is approximately 60 dB difference. The reasons for this difference are reflection, absorption, and multiple internal reflection losses the material provides.

After measuring the first four samples manufactured with unidirectional carbon fiber fabrics, measurements of the other four samples manufactured with bidirectional carbon fiber fabrics were carried out in order to compare two different fabric types in terms of EMI shielding. The attenuation values in dB for the free space and the other four samples between the antennas are given in Table 2.

Table 2. Attenuation values

Frequeny	**Free Space**	**[0°/90°, 0°/90°]**	**[0°/90°, 0°/90°, 0°/90°]**	**[0°/90°, $(0°/90°)_G$, 0°/90°]**	**[0°/90°, $(0°/90°)_G$, 0°/90°, $(0°/90°)_G$, 0°/90°]**
900	-18.82	-25.07	-24.84	-25.37	-24.93
1000	-26.77	-30.93	-30.83	-30.85	-30.71
1100	-18.16	-26.94	-26.18	-26.72	-26.68
1200	-24.55	-33.04	-32.93	-32.35	-32.74
1300	-11.25	-30.39	-31.03	-30.51	-30.75
1400	-10.23	-33.20	-35.82	-34.30	-34.67
1500	-11.20	-33.46	-33.73	-34.39	-35.14
1600	-10.01	-33.39	-33.06	-33.68	-33.43
1700	-11.11	-32.99	-32.99	-32.76	-33.75
1800	-10.44	-33.70	-33.29	-33.45	-33.80
1900	-10.48	-35.00	-35.30	-34.80	-36.21
2000	-8.07	-36.08	-36.78	-35.88	-37.28
2100	-11.01	-41.1	-41.27	-40.88	-41.46
2200	-10.69	-39.62	-40.73	-40.21	-40.65
2300	-9.98	-41.83	-42.48	-42.44	-43.67
2400	-11.46	-43.27	-44.14	-43.98	-43.51
2500	-4.89	-39.82	-40.47	-41.81	-40.05
2600	-16.75	-47.20	-49.48	-49.31	-47.86
2700	-16.28	-53.04	-53.39	-53.26	-51.96
2800	-16.52	-54.14	-53.47	-54.35	-58.33
2900	-15.67	-48.53	-48.07	-48.26	-49.97

3000	-17.27	-51.20	-51.48	-51.99	-51.80
3100	-16.58	-47.18	-47.66	-48.09	-47.26
3200	-16.97	-46.62	-46.64	-47.13	-46.56
3300	-17.29	-53.15	-55.48	-55.55	-51.19
3400	-17.10	-53.83	-54.50	-55.37	-53.81
3500	-17.51	-57.20	-59.06	-57.53	-56.62
3600	-25.64	-67.30	-65.67	-67.53	-65.74
3700	-15.80	-65.19	-62.99	-63.15	-63.24
3800	-15.90	-59.35	-60.67	-60.04	-62.02
3900	-15.51	-61.41	-59.47	-61.18	-62.49
4000	-14.93	-56.22	-53.94	-55.48	-56.21
4100	-14.31	-58.72	-59.58	-60.33	-57.54
4200	-15.53	-60.21	-58.37	-60.15	-60.13
4300	-15.48	-67.11	-73.46	-72.87	-67.15
4400	-15.08	-55.72	-55.03	-55.12	-55.71
4500	-14.89	-55.08	-53.93	-56.30	-54.84
4600	-15.77	-65.41	-63.67	-67.06	-59.85
4700	-16.89	-59.83	-61.98	-61.19	-59.78
4800	-15.47	-72.95	-76.95	-74.36	-77.60
4900	-15.12	-73.31	-69.15	-67.44	-68.75
5000	-16.03	-65.14	-61.63	-60.72	-64.04
5100	-15.80	-69.88	-69.50	-72.66	-65.33
5200	-15.37	-67.74	-68.00	-67.93	-64.78
5300	-15.45	-70.82	-62.06	-62.39	-65.32
5400	-15.28	-68.02	-67.43	-69.45	-63.90
5500	-16.06	-61.30	-60.64	-60.80	-61.03
5600	-14.27	-58.69	-57.06	-56.97	-57.64
5700	-15.73	-69.51	-69.72	-67.59	-67.75
5800	-17.14	-64.62	-61.82	-61.73	-61.45
5900	-15.38	-62.41	-65.53	-61.55	-62.09
6000	-14.38	-70.69	-70.93	-70.71	-71.66

As it can be seen in Table 2, the leftmost column gives the operating frequency. The next column shows the free space loss. The next 4 columns illustrate the received signal strength passing carbon fiber materials with different orientation respectively, [0°/90°, 0°/90°], [0°/90°, 0°/90°, 0°/90°], [0°/90°, $(0°/90°)_G$,0°/90°], and [0°/90°, $(0°/90°)_G$, 0°/90°, $(0°/90°)_G$, 0°/90°].

It can be seen from Table 2 that loss values in the frequency range between 900 and 6000 MHz did not change significantly compared to the samples in [0°, 90°] and [0°, 90°, 0°] orientation prepared with unidirectional carbon fiber fabrics although the volume fraction of carbon fiber was decreased in the samples in [0°/90°, 0°/90°] and [0°/90°, 0°/90°, 0°/90°] orientation prepared with bidirectional carbon fiber fabrics. On the other hand, according to equation (3), shielding effectiveness up to 58.19 dB was achieved with the sample in [0°/90°, 0°/90°] orientation, whereas the sample in [0°, 90°] orientation showed maximum 53.98 dB shielding efficiency. Similarly, maximum shielding effectiveness of 61.48 dB was achieved with the sample in [0°/90°, 0°/90°, 0°/90°] orientation, whereas the sample in [0°, 90°, 0°] orientation showed maximum 60.34 dB shielding efficiency. Therefore, it can be concluded that bidirectional fabric increased EMSE. According to the measurements performed in the 900-6000 MHz frequency range, the attenuation graph of electromagnetic wave for [0°, 90°] and [0°/90°, 0°/90°] orientation is depicted in Figure 8.

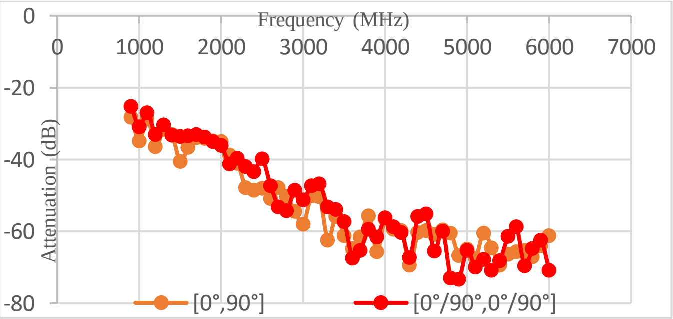


Figure 8. Attenuation for the samples in [0°, 90°] and [0°/90°, 0°/90°] orientation.

According to the measurements performed in the 900-6000 MHz frequency range, the attenuation graph of electromagnetic wave for [0°, 90°, 0°] and [0°/90°, 0°/90°, 0°/90°] orientation is depicted in Figure 9.

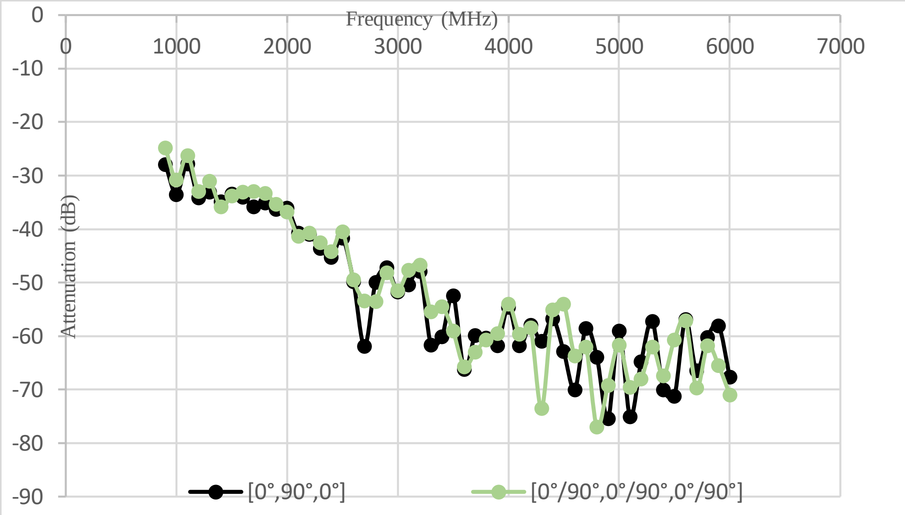


Figure 9. Attenuation for the samples in [0°, 90°, 0°] and [0°/90°, 0°/90°, 0°/90°] orientation.

Also, it can be seen in the table that the use of bidirectional glass fiber has not contributed significantly to EMI shielding. For example, at 2000 MHz and [0°/90°, 0°/90°] orientation, loss is -36,08 dB; however, at orientation [0°/90°, $(0°/90°)_G$, 0°/90°], loss is -35.88 dB. As another example, if the operating frequency is selected as 6000 MHz, at [0°/90°, 0°/90°] orientation, loss is -70.69 dB, but, at [0°/90°, $(0°/90°)_G$, 0°/90°], loss is -70.71 dB.

According to the measurements performed in the 900-6000 MHz frequency range, the attenuation graph of electromagnetic wave for [0°/90°, 0°/90°] and [0°/90°, $(0°/90°)_G$, 0°/90°] orientation is illustrated in Figure 10.

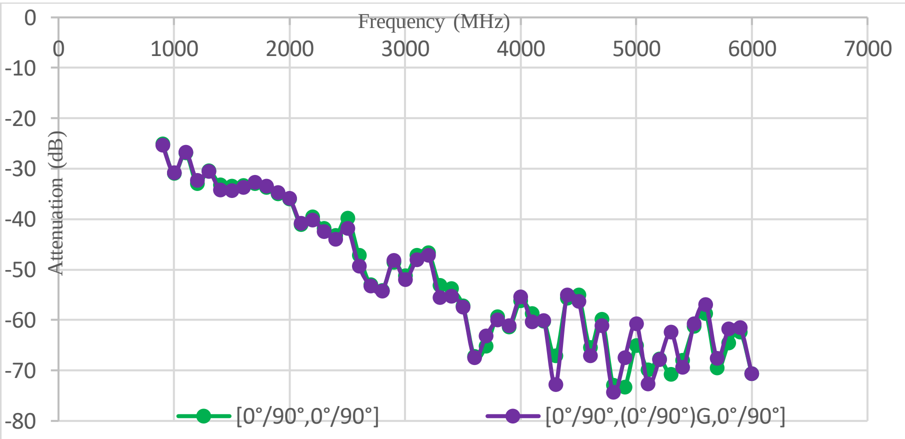


Figure 10. Attenuation for the samples in [0°/90°, 0°/90°] and [0°/90°, $(0°/90°)_G$,0°/90°] orientation.

As can be seen in Figure 10, there is almost the same pattern between the samples. According to the measurements performed in the 900-6000 MHz frequency range, the attenuation graph of electromagnetic wave for the free space and [0°/90°, $(0°/90°)_G$, 0°/90°, $(0°/90°)_G$, 0°/90°] orientation is depicted in Figure 11.

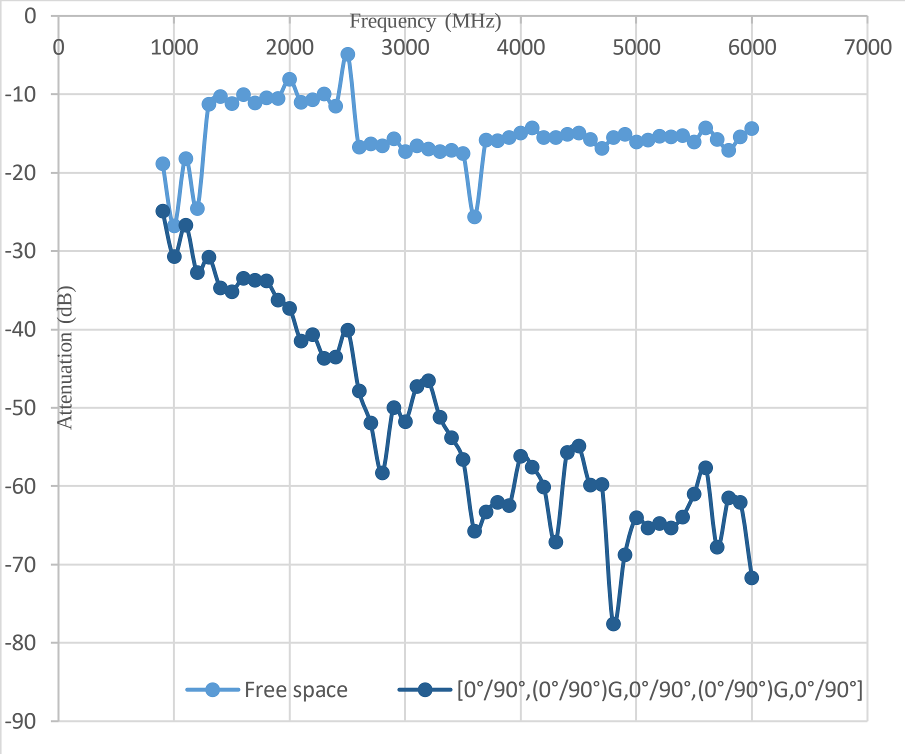


Figure 11. Attenuation for the samples in free space and [0°/90°, $(0°/90°)_G$, 0°/90°, $(0°/90°)_G$,0°/90°] orientation.

As it is seen in Figure 11, attenuation patterns of the material oriented in [0°/90°,$(0°/90°)_G$,0°/90°,$(0°/90°)_G$,0°/90°] and free space are highly different. Especially in high frequencies, there is more than 60 dB difference.

4. Conclusion

In this study, the electromagnetic interference (EMI) shielding characteristics of carbon fiber epoxy composite samples manufactured were investigated. The measurement results indicated that carbon fiber could be utilized as a shielding material. In order to increase the shielding abilities of carbon fiber reinforced polymer composites (CFRP), it was verified that the fiber orientation was one of the most effective parameters. It was observed that the electromagnetic shielding effectiveness (EMSE) increased since the absorption loss of electromagnetic wave increased when the orientation angle is 90°, which is perpendicular to the electromagnetic wave propagation direction. Another parameter that affected the EMI shielding was fabric type. It was observed that use of bidirectional fabrics increased the EMSE. Furthermore, according to the results, the number of plies has fewer effects on EMSE than the orientation angle. Therefore, when designing composite laminates involving carbon fibers, determining the most effective fiber orientation, rather than increasing the number of plies, is suggested to provide a better shielding.Also, the cost will reduce since the use of the redundant fiber fabric and epoxy resin is avoided.

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References

[1] Chung, D. D. L. (2001). Electromagnetic interference shielding effectiveness of carbon materials. *Carbon*, 39: 279-285.

[2] Kim, H. G., Shin, H. J., Kim, G. C., Park, H. J., Moon, H. J. and Kwac, L. K. (2014). Electromagnetic interference shielding characteristics for orientation angle and number of plies of carbon fiber reinforced plastic. *Carbon letters*, 15: 268-276.

[3] Arik, E. and Tabakcioglu, M.B. (2017). Reducing emi by multiple slits shielding, *9th International Conference on Electronics, Computers and Artificial Intelligence*, pp. 1-4.

[4] Ding, S.J., Zhao, Y.Z., Ge, D.B. (2008). Research progress in electromagnetic shielding materials. *Materials Review* 22.4.

[5] Williams, N., Varadan, V.K., Ghodgaonkar, D. and Varadan, V.V. (1990). Measurement of transmission and reflection of conductive lossy polymers at millimeter-wave frequencies. *IEEE transactions on electromagnetic compatibility*, 32: 236-240.

[6] Rea, S., Linton, D., Orr, E. and McConnell, J. (2005). Electromagnetic shielding properties of carbon fibre composites in avionic systems. *Mikrotalasna revija*, 11: 29-32.

[7] Amran, Y. M., Alyousef, R., Alabduljabbar, H., Alaskar, A., & Alrshoudi, F. (2020). Properties and water penetration of structural concrete wrapped with CFRP. *Results in Engineering*, *5*, 100094.

[8] Liu, Z., Zhou, Z., & Hou, Q. (2021, October). Improvement on Electric Conductivity of Carbon Fiber Reinforced Plastic Composites. In *2021 IEEE 5th Information Technology, Networking, Electronic and Automation Control Conference (ITNEC)* (Vol. 5, pp. 632-635). IEEE.

[9] Jana, P. B., Mallick, A. K. and De, S. K. (1992). Effects of sample thickness and fiber aspect ratio on emi shielding effectiveness of carbon fiber filled polychloroprene composites in the x-band frequency range. *IEEE transactions on electromagnetic compatibility*, 34: 478-481.

[10] Jones, R. M. (1975). *Mechanism of composites materials*, McGraw-Hill Book Co., New York, 2nd Edition.

[11] Mohan, L., Kumar, T. N., Karakkad, S., & Krishnan, S. T. (2021). Development of Cost-Effective Carbon Nanofiber Epoxy Nanocomposites for Lightweight Wideband EMI Shielding Application. *IEEE Transactions on Nanotechnology*, *20*, 627-634.

[12] Luo, X., & Chung, D. D. L. (1999). Electromagnetic interference shielding using continuous carbon-fiber carbon-matrix and polymer-matrix composites, *Composites Part B: Engineering*, *30*(3), 227-231.

[13] Ucar, N., Kayaoğlu, B. K., Bilge, A., Gurel, G., Sencandan, P., & Paker, S. (2018). Electromagnetic shielding effectiveness of carbon fabric/epoxy composite with continuous graphene oxide fiber and multiwalled carbon nanotube. Journal of Composite Materials, 52(24), 3341-3350.

[14] Jaroszewski, M, Thomas, S., Rane, A.V. (2018). Advanced materials for electromagnetic shielding: fundamentals, properties, and applications. John Wiley & Sons.

[15] Sultan Aljibori, H.S., Mohamad Alosfur, F.K., Ridha, N.J. and Salim, S. (2016). A study on thermal diffusivity and dielectric properties of epoxy matrix reinforced by fibers material. *Journal of Kerbala University*, 12: 42-53.

[16] Coskun, Y. and Tabakcioglu, M.B. (2021). Electromagnetic Shielding Characteristics of Oriented Carbon Fiber Epoxy Composites", *EMC Turkey Conference*, Submitted.